MISSOURI RIVER DESIGN STUDY

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LABORATORY INVESTIGATION OF UNDERWATER SILLS ON THE CONVEX BANK OF POMEROY BEND

MEAD HYDRAULIC LABORATORY
MEAD, NEBRASKA

U. S. ARMY ENGINEER DISTRICT, OMAHA
U. S. ARMY ENGINEER DISTRICT, KANSAS CITY
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This report presents the results of a model study performed on Pomeroy Bend at the Mead Hydraulic Laboratory. The study was performed by personnel of the Channel Stabilization Section and the Hydraulics and Sediment Section of the Omaha District, Corps of Engineers, under the general supervision and guidance of the Kansas City District and the Missouri River Division.

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DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

Laboratory Investigation of Underwater Sills on the Convex Bank of Pomeroy Bend
Conducted at
Mead Hydraulic Laboratory
Mead, Nebraska

U. S. ARMY ENGINEER DISTRICT, OMAHA, NEBRASKA
U. S. ARMY ENGINEER DISTRICT, KANSAS CITY, MISSOURI
MISSOURI RIVER DIVISION, OMAHA, NEBRASKA

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LABORATORY INVESTIGATION OF UNDERWATER SILLS ON THE CONVEX BANK OF POMEROY BEND

INTRODUCTION

This report presents the results of a model study performed on Pomeroy Bend at the Mead Hydraulic Laboratory. The study was performed by personnel of the Channel Stabilization Section and the Hydraulics and Sediment Section of the Omaha District, Corps of Engineers, under the general supervision and guidance of the Kansas City District and the Missouri River Division.

Attempts to improve and control the Missouri River have been in progress for many years. Various arrangements of dikes, sills, and revetments have been constructed to control the overall river alignment and to insure a river channel of adequate depth and width for navigation purposes. The overall bank alignment of the Missouri River between Sioux City, Iowa and St. Louis, Missouri has in general been established with the shape of each major bend controlled by a combination of spur dikes and bank revetment. However, many times within this general alignment, problems still appear at given locations. One of the more prevalent problems encountered is maintaining an adequate navigation channel through a long flat bend.

DESCRIPTION OF POMEROY BEND

A typical example of such a bend in the Missouri River is Pomeroy Bend located just north of Kansas City, Missouri. The concave (outer) bank of the bend is completely revetted with rock which forms a stabilized boundary. Only at isolated locations will breaks or openings for localized drainage outlets into the river appear in the concave bank. The convex bank, or inside of the bend, is controlled by a series of spur dikes spaced intermittently throughout the bend. These dikes are spaced

closer together near the upstream portion of the bend and are progressively farther apart as you proceed through the reach. At normal stages these spur dikes are well above the water surface elevation. Plate 9 shows the construction which had taken place prior to 1964 in the bend.

The 1962 hydrographic survey revealed that the flow entering the reach was concentrated along the concave bank. However, in the vicinity of River Mile 381.5, near spur dike 406.0, the flow left the concave bank and crossed to the convex side. Throughout the remainder of the bend frequent minor crossings were also evident.

In 1964, the Kansas City District started construction of a series of underwater sills in an attempt to concentrate the flow along the concave bank. A total of 9 rock sills, located off the end of existing dikes, were constructed. Each sill was 200 feet long, and the crest was approximately 2.0 feet below the normal water surface. Because of their low crest elevation they were still capable of passing the infrequent high flood discharges.

Considerable improvement was noted in the bend after this phase of construction. An inspection of the 1965 hydrographic survey one year after the installation, Plate 9, indicates that depths of 12 to 15 feet were present throughout most of the reach. However, there later appeared to be a tendency for bars to still form in the lower one-half of the concave side of the bend, although no change in the construction had taken place. These problems are still evident in the bend.

PURPOSE OF STUDY

Design criteria for the effective control of bends similar to Pomeroy Bend are very limited. Underwater sills of the type used in this bend have been installed at various locations along the Missouri River with

varying degrees of success. There exists a multitude of combinations of sill lengths, heights, angles, and shapes which could be constructed. Some give a good positive control, and others have little or no effect on the overall channel characteristics. Because of the many variations possible, the problem of effectively controlling the flow through a long flat bend by the use of underwater sills on the convex bank was chosen for a detailed study in the laboratory. Emphasis was also placed on determining what additional construction would be required in Pomeroy Bend in order to improve existing conditions. With these two thoughts in mind, the following test objectives were undertaken:

1. Study the effect of underwater sills placed at various heights, lengths, spacing, and angle on the convex bank of flat bends.

2. Determine the effect of using a predetermined construction sequence when installing a series of structures in a given bend.

3. Study the performance of underwater sills when subjected to unusually high discharges.

4. Study the performance of the existing structures in the prototype, and recommend additional construction which might improve the channel in this reach.

MODEL VERIFICATION

Verification of a river model involves the determination of a set of model dimensions by which the model will act and react to changes much in the same manner as is known to exist in the prototype. The horizontal scale, or length dimension, for this test was predetermined by the physical size of the building and the length of the reach to be studied. The vertical scale, or height dimension, as well as the velocity scale were determined through a series of verification studies.

One method of determining scales which is used widely in hydraulic models is to keep the Froude number equal between the model and prototype. The use of this relationship allows one to set both the vertical and velocity scales. However, in a movable bed model an additional variable is present which does not appear in the Froude number. This is the rate of sediment movement, both in suspension and along the bed. The method by which sediment moves and deposits is not only related to such things as the depth and velocity, but is also dependent upon such things as the individual grain characteristics, bottom roughness, intensity of turbulence, and the width depth ratio of the stream. Physical dimensions of the available space dictated that it would not be possible to use the same horizontal scale as vertical scale. This not only results in a distortion of the above factors, but it also tends to distort the shape of the bed formations.

Preliminary tests revealed that the model would not reproduce the prototype if the Froude relationships were followed. Prototype measurements indicated that before the installation of the sills the river was in an unstable, meandering condition, and it was therefore important that we reproduce these conditions in the model. To assist in the selection of a correct set of scales, a series of tests were conducted in which the depth and velocity were varied. This permitted observation of the bed formation and the channel characteristics under a range of conditions. A summary of these tests is shown in graphical form on Plate 4. The points on this graph are divided into three groups or classifications. The first group consists of the tests in which the channel was definitely in a meandering state, with no clear cut channel

evident throughout the bend. These points are located toward the left portion of the plot. In contrast, another group of points is labeled as concave flow. These points, located at the right of the plot, indicate tests in which the channel was well defined and the flow was concentrated along the outer or concave bank throughout the entire reach. In between these two regions, there were combinations of depth and velocity where the channel was not clearly defined either as concave or meandering flow. These are labeled as being in a transition range. The solid line shown on this plot shows combinations of depth and velocity which satisfy the Froude criteria. Combinations of depth and velocity in the meandering region do not fall on this curve and indicate why it was not possible to satisfy the Froude criteria. Only at very shallow depths, in the range of 0.10 ft., do these points approach the curve. However since it is difficult to operate a model using very shallow depths, it was necessary to choose a set of dimensions where the depth approach 0.2 ft., and a corresponding velocity which would fall in the meandering range. The numbers beside each point indicate the measured energy slope through the test region.

Since the channel was altered considerably by construction of the underwater sills, this gave a second set of known conditions for verification of the model. Using the scale relationships which satisfactorily reproduced the prototype prior to installation of the underwater sills, the model was reconstructed with the underwater sills. The model was then placed in operation and the scales adjusted until a combination was found which would reproduce the prototype under both known conditions. This does not mean that each bar and dune was literally reproduced in

the model, but that the model was in the same state or regime of flow as the prototype. A comparison of model and prototype cross sections is presented on Plate 3, and a satisfactory reproduction is evident. Bed maps comparing model and prototype are shown on Plate 9.

Using the results of these tests as a guide, a complete set of model scales was then adopted for the discharge to be studied. Since the average discharge during the navigation season is essentially the dominant bed forming discharge, only one basic discharge was used for the entire remaining study. No attempt was made to reproduce a seasonal runoff hydrograph, since a completely new set of scale relationships would be necessary for each discharge involved. The final scale relationships adopted for this study are listed in Table 1.

TABLE 1

	Missouri River Pomeroy Bend	Model, Run 27B [1]	Scale Ratio Prototype/Model
Discharge, cfs	35,500	0.332	107,000
Average Depth, ft.	10.70	0.185	58
Channel Width, ft.	750	5.0 ft	150
Average Velocity, fps	4.08	0.358	11.4
Slope, ft/ft	0.00020	0.0010	0.20
Manning's "n"	0.025	0.044	0.57
Specific Gravity of Bed Material	2.65	1.30	2.04
D_{35}	0.260 mm	0.280 mm	0.93
D_{50}	0.300 mm	0.300 mm	1.00
D_{65}	0.380 mm	0.330 mm	1.15
Froude No.	0.220	0.146	1.51

TABLE 1 (Cont'd)

	Missouri River Pomeroy Bend	Model, Run 27B [1]	Scale Ratio Prototype/Model
Intensity of shear on the bed, ψ'	1.865	14.13	0.132
Intensity of bed load transport, ϕ'	3.60	0.045	80
Intensity of bed load transport, ϕ, if sand were used in model	3.60	0.0001	36,000 [2]
Settling velocity of bed material, fps	0.116	0.0314	3.7
Total sediment load using walnut shells, Q_s			95,000 [2]
Total sediment load if sand were used, Q_s			5,400,000 [2]
Sediment time ratio using walnut shells, T_s			27 [2]
Sediment time ratio if sand were used, T_s			0.25 [2]

1 Run 27B is used as a comparison, since it is a reproduction of the prototype conditions.

2 Estimated values based on methods developed by Einstein.

TEST PROCEDURE

The model basin used for this test was a completely closed system which recirculated both the water and the bed material. The water depth in the model was controlled only by regulating the amount or volume of water in the entire system. No tailgate or depth control structure of any kind was used, and therefore the water surface and bed slopes were free to adjust themselves. At the beginning of a test a considerable amount of shifting of bed material was usually evident. However, after the model had been in

operation for some period of time, an equilibrium condition would finally be achieved. This does not mean that material was no longer in movement, but drastic changes were no longer visible. A method used to establish when equilibrium conditions had been achieved was continuous monitoring of the water surface slope. Initially the slope might change rapidly, but as time progressed the slope would stabilize at some constant value. This usually occurred after 8 to 10 hours of operation, and indicated when equilibrium had been established in the model. The slope was determined by the use of impact tubes located approximately 10 feet apart in the flume and connected to a bank of stilling wells from which very accurate measurements were possible. One set of these measurements is shown on Plate 2. Since the impact tubes measure the total energy, the slope of the energy grade line was measured directly.

At the completion of a test, the basin was either drained or flooded depending upon which method was used to sound the bed. During the early period of testing the flume was always drained, and a hand depth measuring device was used to determine the bed elevations. In a few of the tests the actual water depth was measured with the flume still in operation. In the last group of tests, after the completion of the run, the still water level was raised and the cross section was sounded with a sonic depth sounding apparatus. This gave a true picture of the cross section on a continuous X-Y plot from which the initial water depths could be determined. A sample of the data obtained from the plotter is shown on Plate 2.

DATA ANALYSIS

With the closed recirculating basin it was very difficult to control or predict the final water depth in advance. It was possible to control

the water surface elevation at some point near the center of the flume around which the water surface slope would vary. The true average depth during a test could not be determined until after the completion of a test when cross sections were measured.

After the scale relationships had been determined it would have been desirable to keep the average water depth constant during the remaining tests. However, due to the reasons discussed above, small variations in the average depth did exist. In order to compensate for this, an adjustment was made in those tests where the average depth was significantly different from the base test, Run 27B. This was accomplished by adjusting the recorded depths by the ratio, $\frac{d_x}{d_B}$, where d_x is the average depth of a given test and d_B is the average depth in Run 27B. This permitted a more accurate correlation and comparison between the various test runs. The corrections necessary were usually very small, and ranged from 0 to 4% of the depth. The hydraulic computations, however, used the true average water depth as determined by measurements.

Table 2 is a summary of the measured data and the hydraulic computations made for each test. The basic quantities; discharge, average depth and energy slope are average values of measurements taken during or after a test. The remaining items are functions of these basic quantities and can be used to compare one test against another. A large part of the analysis of a model study of this nature is based on the observation of the bed configuration at the completion of each test. The degree of channel control, which has been previously mentioned, indicates the ability of a given arrangement of structures to control meandering in the reach, and whether or not the resulting cross section is acceptable

for navigation purposes. Methods to relate this channel condition to basic hydraulic calculations are very difficult. Since most of the tests were run basically at the same depth and discharge, changes in the bed formations or hydraulic functions were assumed to be a result of changes in the structure configuration. A description of each item shown in Table 2 is as follows:

Column (1) Run Number

Column (2) Discharge - The average discharge in the model during the testing period.

Column (3) Cross Sectional Area - The average flow area of the measured cross sections. These sections were taken at representative locations throughout the study reach. No sections near the ends of the structures are included in this average, since many times a large scour hole was present in these areas.

Column (4) Average Depth - The cross sectional area divided by the top width. For computation purposes the average depth is assumed to be equal to the hydraulic radius.

Column (5) Average Velocity - The average discharge divided by the average cross sectional area.

Column (6) Energy Slope - The slope of the energy grade line as determined by laboratory measurements near the end of each test.

Column (7) R' - A measure of the hydraulic roughness caused by the individual grains that form the bed. It is computed from the following formula:

$$V = 5.75 \sqrt{SR'g} \log_{10} \left(12.25 \frac{R'}{D_{65}}\right)$$

in which V = average velocity
S = energy slope
R' = grain roughness
D_{65} = the grain diameter at which 65% by weight of the material is finer (D_{65} for the bed material used in this study = 0.325 mm)

Column (8) R" - A measure of the roughness caused by the bars and other boundary irregularities. It is computed from $R'' = R_T - R'$, where R_T = the hydraulic radius, and R' = as given above.

Column (9) R'/R_T - A ratio which indicates the relationship between the grain roughness and the total roughness.

Column (10) Ψ' - The intensity of shear on the bed as defined by Einstein and Barbarossa(1).

$$\Psi' = \frac{S_s - S_f}{S_f} \frac{D_{35}}{R'S}$$

Where S_s = Specific gravity of the solids = 1.30
S_f = Specific gravity of the fluid = 1.00
D_{35} = The grain size at which 35% by weight is finer = 0.290 mm.
R' & S = As previously defined.

Column (11) Manning's "n" - Composite roughness as computed from:

$$n = \frac{1.486\, AR^{2/3} S^{1/2}}{Q}$$

Where A = Average area
R = Hydraulic radius = average depth
S = Energy slope
Q = Average discharge

Column (12) The Froude No., $F = \frac{V}{\sqrt{gd}}$ represents the ratio of the inertia forces to the gravitational force as they existed in the model.

(1) Einstein, H. A. and Barbarossa, N. L. "River Channel Roughness" Transactions, ASCE, Vol. 117, 1952.

TABLE 2

SUMMARY OF HYDRAULIC COMPUTATIONS

1	2	3	4	5	6	7	8	9	10	11	12
Run Number	Average Discharge cfs	Average Flow Area ft^2	Average Depth ft	Average Velocity fps	Energy Slope ft/ft	R' ft	R' ft	R'/R_T	ψ'	Manning's "n"	Froude Number F
27B	0.332	0.971	0.185	0.342	0.000967	0.0209	0.1641	0.1130	14.13	0.0439	0.140
28B	0.378	0.996	0.200	0.380	0.000834	0.0262	0.1740	0.1310	13.07	0.0388	0.150
29A	0.359	1.043	0.208	0.344	0.000759	0.0260	0.1820	0.1250	14.44	0.0427	0.133
29B	0.359	0.969	0.195	0.370	0.000712	0.0240	0.1660	0.1490	15.66	0.0361	0.148
29C	0.359	0.998	0.199	0.360	0.000690	0.0280	0.1670	0.1410	14.79	0.0443	0.142
29D	0.359	0.893	0.184	0.402	0.000844	0.0285	0.1555	0.1550	11.88	0.0349	0.165
29E	0.359	1.018	0.199	0.353	0.000706	0.0275	0.1710	0.1380	14.72	0.0361	0.139
29F	0.359	1.013	0.209	0.357	0.000758	0.0275	0.1700	0.1320	13.73	0.0404	0.137
29G	0.359	1.034	0.202	0.347	0.000794	0.0252	0.1720	0.1250	14.27	0.0395	0.153
30A	0.359	1.001	0.197	0.359	0.000790	0.0320	0.1650	0.1620	11.29	0.0395	0.142
30B	0.359	1.030	0.204	0.349	0.000730	0.0330	0.1710	0.1620	11.68	0.0399	0.136
30C	0.359	0.905	0.178	0.397	0.000806	0.0290	0.1490	0.1630	12.22	0.0336	0.166
30D	0.359	0.968	0.188	0.371	0.000907	0.0281	0.1603	0.1490	11.21	0.0396	0.151
30E	0.359	0.994	0.194	0.361	0.000774	0.0272	0.1668	0.1402	13.57	0.0383	0.144
30F	0.359	0.977	0.196	0.367	0.000833	0.0250	0.1710	0.1276	13.71	0.0393	0.146
31A	0.359	0.985	0.202	0.365	0.000856	0.0245	0.1780	0.1213	13.62	0.0411	0.143
31B	0.358	0.978	0.196	0.366	0.000738	0.0230	0.1683	0.1426	13.82	0.0373	0.145
31C	0.361	1.016	0.200	0.355	0.000775	0.0262	0.1733	0.1313	14.07	0.0399	0.140
31D	0.359	0.969	0.190	0.371	0.000839	0.0255	0.1675	0.1340	13.35	0.0385	0.151
32G	0.359	0.862	0.168	0.417	0.000926	0.0278	0.1402	0.1655	11.09	0.0329	0.179
33C	0.359	0.858	0.170	0.419	0.000967	0.0258	0.1445	0.1515	11.44	0.0338	0.179

TABLE 2

SUMMARY OF HYDRAULIC COMPUTATIONS (Cont'd.)

1	2	3	4	5	6	7	8	9	10	11	12
Run Number	Average Discharge cfs	Average Flow Area ft^2	Average Depth ft	Average Velocity fps	Energy Slope ft/ft	R' ft	R" ft	R'/R_T	ψ'	Manning's "n"	Froude Number F
34D	0.359	0.786	0.153	0.457	0.001042	0.0296	0.1232	0.1937	9.25	0.0300	0.206
35A2	0.359	1.033	0.200	0.348	0.000912	0.0222	0.1782	0.1108	14.10	0.0441	0.137
35B2	0.359	0.882	0.159	0.407	0.000960	0.0265	0.1323	0.1669	11.22	0.0332	0.180
36A	0.359	0.991	0.194	0.362	0.000811	0.0255	0.1686	0.1314	13.83	0.0392	0.145
36A1	0.359	0.931	0.181	0.386	0.000821	0.0267	0.1538	0.1479	13.00	0.0354	0.159
36B	0.359	0.906	0.184	0.396	0.000743	0.0305	0.1535	0.1657	12.62	0.0330	0.163
36D	0.359	0.878	0.187	0.409	0.000903	0.0285	0.1589	0.1521	11.10	0.0356	0.166
36E	0.359	0.987	0.189	0.364	0.000953	0.0232	0.1655	0.1229	12.90	0.0414	0.148
36F	0.359	0.959	0.182	0.374	0.000950	0.0242	0.1580	0.1328	12.40	0.0395	0.155
37A	0.359	0.983	0.196	0.365	0.000883	0.0245	0.1718	0.1248	13.22	0.0423	0.145
37B	0.359	1.015	0.200	0.354	0.000789	0.0260	0.1737	0.1302	13.94	0.0403	0.139
37C	0.359	0.784	0.167	0.458	0.000823	0.0353	0.1313	0.2119	9.85	0.0283	0.198
37D	0.359	0.785	0.167	0.457	0.000731	0.0393	0.1274	0.2376	9.95	0.0267	0.197
37E	0.359	0.738	0.153	0.486	0.000702	0.0439	0.1094	0.2864	9.28	0.0234	0.219
37F	0.359	0.817	0.165	0.439	0.000714	0.0376	0.1276	0.2273	10.67	0.0274	0.190
38A	0.359	0.844	0.172	0.425	0.000781	0.0331	0.1389	0.1924	11.06	0.0303	0.181
38B	0.359	0.849	0.182	0.423	0.000724	0.0388	0.1330	0.2258	10.18	0.0293	0.179
38C	0.359	0.867	0.178	0.414	0.000760	0.0326	0.1459	0.1826	11.51	0.0313	0.173
38D	0.359	0.914	0.184	0.393	0.000764	0.0306	0.1538	0.1659	12.23	0.0336	0.177
39A	0.359	1.013	0.196	0.354	0.000787	0.0255	0.1707	0.1300	14.25	0.0398	0.141
39B	0.359	0.973	0.190	0.369	0.000694	0.0289	0.1609	0.1523	14.40	0.0349	0.150

DESCRIPTION OF MODEL TESTS

All of the tests covered in this report were made on a model of the Pomeroy Bend reach of the Missouri River. The model began at Structure 406.6 near river mile 382 and terminated at Structure 404.0 near river mile 379. All of the tests performed centered around the use of underwater sills on the convex bank of the bend as the solution to the problem, and no attempt was made to compare these results with other means of control. It should be recognized that there are other methods which can be considered when controlling bends of this type, and the use of underwater sills may not be the best solution for a given case. The tests are primarily a comparison between various types of underwater sills, and the results should be applied only to bends which are similar in shape and have comparable flow characteristics.

The model tests were divided into groups or series in which some of the primary functions were held constant while others were allowed to vary. A short description of each series, along with the conclusions and impressions gained from the tests follow. The first 28 tests were concerned with model verification, and only the final results of this group of tests, Tests 27B and 28B, are included in this report. Table 3 lists the primary variables for each major test.

Test Series 29. (Refer to Plates 10 and 11)

Purpose. This series of tests was performed to observe the effects of underwater sills placed on a convex bank when the structures were equally spaced throughout the bend. The sill length, height, and angle to flow were held constant as listed in Table 3. The number of sills varied from a minimum of 1 in Run 29A to a maximum of 20 in Run 29F.

Results. In order to insure concave flow throughout the bend with little or no tendency for the streamlines to meander, it was necessary to place the sills at 7-1/2' spacing in the model. This corresponds to approximately 1,125 feet in the prototype. One test (Run 29F) was tried with the sills spaced only 5' apart in the model, and little or no improvement in the overall channel was noted. The closer spacing tested in Run 29F did result in a more smooth convex bank line, due to the fact that more bed material was trapped or deposited between the sills. If this accumulation of material and corresponding loss of storage area is a desirable characteristic in a bend of this type, a closer spacing might be justified.

Test Series 30. (Refer to Plates 12 and 13)

Purpose. The objective in this series of tests was to study how sills placed at an angle to the flow or constructed with a sloping crest would affect the channel characteristics. The length of the model sills was held constant at 1.33' and the spacing, except in Run 30A, was held at 7.5', corresponding to the optimum spacing noted in the 29 series. In Runs 30A through 30E, the sills were at an angle to the flow and had level crests. In Run 30F the sills were normal to the flow, but had sloping crests.

Results.

a. It should be noted that the sills were held to a constant structural length rather than being extended to a common flow line as established by right angle sills; thus, at different sill angles the encroachment on the total cross section varies, and can result in entirely different overall channel characteristics. Run 30F in which the sloping sills were normal to the flow can be compared directly with Run 29G.

b. This group of studies did show some distinct differences in the ability of the various shapes to control a channel. Sills which were pointed upstream into the flow appeared to divert the flow toward the concave bank more than any shape studied. However, several undesirable characteristics were also revealed. It was apparent that a small component of the flow would be held against the upstream face of these structures and be directed toward the bank. This component would then attempt to cross over the structure at the intersection of the structure and the bank line, and remain concentrated behind the back of the fill downstream of the structure. This resulted in a small chute next to the bank line. The presence of this component could also result in the accumulation of trash or ice being caught in these locations.

c. When the sills were directed downstream 15° from perpendicular, (75° to the flow), the channel almost went back into a semi-meandering condition. They appeared to have very little effect on diverting the water away from the convex bank and in some cases appeared to attract or pull the flow that passed over them to remain behind the structures.

d. The sloping sill arrangement studied in Run 30F was not as effective in diverting the flow as the runs using level structures. The action of the water passing over a sloping sill was notably different from that which was visible in previous tests. The circular eddy pattern visible off the ends of regular dikes would not completely develop. Because of this, there appeared to be a tendency for the rate of filling behind a sloping sill to be somewhat increased; however, the total amount of fill or deposition was less than when using perpendicular level sills. The size of the scour hole at the end of the sills was greatly reduced when using a sloping crest.

Test Series 31. (Refer to Plate 14)

Purpose. This series of tests was patterned after the 29 series in which it was desired to arrive at an optimum structure spacing in the bend using equally spaced sills. In this group of tests, the length of the sills was increased from 1.33' to 2.00' in the model, (200' to 300' in prototype), and the remaining functions; length, height and angle were held constant.

Results. These tests showed that the length of the sill has a definite influence on sill spacing. Sills placed an average of 10' in the model (1500' in prototype) gave a good navigable channel. The one disadvantage noted in the increased length was the corresponding increase in the velocity in the open portion of the channel, and reduction in the navigation channel width.

Test Series 32. (Refer to Plate 15)

Purpose. This group of studies was run to study the effect of placing structures in the model where it appeared they were needed. No set structure spacing was used, but the length, height and angle were held constant throughout the series. The procedure used was to install one sill at the extreme upstream end of the bend and then allowing the entire reach to come to an equilibrium condition. After observing the flow characteristics and noting the location of the deposits, a second sill would be installed. The bed configuration was altered as little as possible between the tests. This procedure was followed until the entire bend was completely under control and a stable channel resulted.

Results.

a. This test series showed that there may be definite advantages in a phased or unit type of construction in the control of a bend. Our tests

showed that by starting at the upstream end of a bend and proceeding throughout the reach, the average structure spacing was increased in comparison to equally spaced structures. The final test in this series, 32G, gave a completely controlled channel with a total of only 7 sills, whereas 10 equally spaced sills were required to achieve the same degree of control.

b. It became readily apparent that locating structures by this method can be very difficult and requires a great deal of judgment. What may first appear to be the logical location for a structure does not always prove to be the best place in reality. Many times the flow characteristics are completely altered by the installation of an additional structure, and it was apparent that a better location might have been chosen. The procedure used in this series also showed that the effectiveness of a structure to influence the flow pattern changes as deposition occurs behind it. The sills installed at the upstream end in the first part of the series were subjected to flow for a greater length of time than those installed in the lower portion. The action of the flow over and around a structure that has no deposition behind it is significantly different from one where a large build-up has had an opportunity to develop. This procedure could not be recommended unless the final structure layout could be determined by model testing prior to construction, or unless model testing could be conducted concurrently with construction in the river with the model helping to determine the next step of prototype construction.

<u>Test Series 33 and 34</u>. (Refer to Plates 16 and 17)

<u>Purpose</u>. The purpose of this group of tests was the same as test Series 32 in which structures were placed at random where it appeared they

were necessary. The 33 series tests differed from the 32 series in that the sill crests were constructed with a uniform slope from the water surface elevation at the convex bank line to 0.10 ft. below the water surface (6.0 ft. in prototype) at the end of the structure. The sill length (2.0 ft. in model, 300 ft. in prototype) used in these tests was the same as the 32 test series. In the 34 test series sloping sills were used which sloped from zero at the bank line to 0.15 ft. at the end (9.0 ft. in prototype).

Results.

a. The results as described in the 32 series tests apply for this group also. The unique action of the flow around a structure with a sloping crest was again evident. The amount of turbulence off the ends of these structures was greatly diminished, which had the two-fold effect of reducing the size of the scour hole and a corresponding increase in the rate of deposition behind the structure.

b. A comparison between the 32 and 33 series also indicated that attempts to force the flow toward the concave bank with one big push as was done in the 32 series may cause problems farther downstream. In the 32 series, the flow had previously occupied the full 5 foot channel width and suddenly was forced to occupy only 3 ft. of channel. This abrupt contraction appeared to cause the stream lines to be pushed against the concave revetment with such force that they were reflected toward the convex bank farther downstream. The sloping sills used in the 33 series did not influence the flow to this same degree, and this resulted in a somewhat smoother entrance condition.

c. The 34 series tests, where a steeper crest slope was used, were not as effective in keeping the flow concentrated along the concave bank

as when less slope was used. One additional sill was required to obtain the same degree of control. At the completion of Run 34D, the model was subjected to an increased discharge and depth to observe the effects of unusually high flows. Very little difference was noted in the overall channel characteristics, however some of the material which had previously deposited behind the structures was removed during the high flows. The concave flow pattern which had previously developed was still maintained.

Test Series 35, 36 and 39. (Refer to Plates 18, 19 and 20)

Purpose. This group of tests concentrated on a more detailed study of existing conditions of Pomeroy Bend. Recent hydrographic surveys have indicated that there is still a tendency for bar formations to develop in the lower one-half of the bend even though several sills along the convex bank have been placed in the river. These tests were performed to see what additional construction might be placed in the bend to give further control in the area.

Results.

a. Several different layouts were constructed and tested in the model. Test 35B2 was a test where one additional sill was placed off the end of existing structure 405.15. This resulted in a series of very closely spaced dikes, and little or no benefit to the channel was noted. In the 29 series it was found out that after the sills were spaced closer than 7-1/2 ft. in the model (1,125 ft. in prototype) the only real benefit which was noted was slightly more deposition between the sills. The closer spacing did not appear to alter the remaining channel significantly. This same condition was observed in this test.

b. Run 36A was a test in which the Pomeroy Bend conditions were again reproduced, only here two of the previously installed sills

(405.0 and 406.0-B) were extended to a total length of 2.0 ft. in the model (300 ft. in prototype) and the remaining structures left unaltered. This simple addition gave a very good channel through the major portion of the reach, with little or no tendency for material to deposit in the lower one-half of the bend. In Run 36B one additional sill (404.7) was extended and again, good positive control was maintained throughout the bend.

c. Several other modifications were also tried. In Run 36A1 the sill at the very entrance to the reach (404.0) was extended as well as the three mentioned in Test 36B. However, this abrupt contraction appeared to cause considerable disturbance in the flow and resulted in a bar formation near dike 404.7.

d. In Run 36E, the extensions from the ends of structures 405.0, 406.0-B and 405.6 were installed at an angle to the flow. The addition of these extensions had very little effect on diverting the flow. Observations made during this test indicated that the extension may have caused a component of the flow to be drawn back in behind the structures; thus prohibiting deposition in this area. Run 36F was a test in which the L-shaped extensions were parallel with the flow. These extensions were constructed off the ends of sills 404.7, 405.0, 406.0-B and 405.6. The presence of these extensions appeared to encourage the flow to concentrate next to them, and no direct benefit to the overall channel was noted. These L-shaped structures did induce a considerable amount of deposition behind them. The scour holes around these structures were likewise reduced.

Test Series 37 and 38. (Refer to Plates 21, 22 and 23)

Purpose. The 37 and 38 test series were patterned after the 32 series in which structures were placed in the model in stages, beginning at the upstream end and proceeding through the bend. These tests differed

in that both the length and the spacing were allowed to vary between the structures. Level sills were used for the 37 series, whereas sloping sills were used for the 38 series tests.

Results. These tests began by using sills only 1.33 ft. long in the model (200 ft. in prototype), which is equivalent to the length of the sills previously existing in Pomeroy Bend. The length of the structures was increased until they reached 2.50 ft. in the model (375 ft. in prototype). The final test in this series (37F) ended with excellent control while using only 6 sills. It appears that if control is maintained in the upper one-half of a bend, considerably less effort is needed to continue this degree of control through the lower portion of the bend. It also became apparent that the variable length and spacing concept may have applications and advantages over the use of constant dimensions.

CONCLUSIONS

The model showed that when the sills were equally spaced throughout the convex side of a bend, 90° to the flow and 0.03' below the water surface, the maximum horizontal spacing necessary to insure concave flow was 7.5' (or approximately 1,125 ft. apart and 1.80' below water in prototype). There was very little improvement noted to the navigation channel when the sills were placed closer together. An increase in the accumulation of material between the structures on the convex bank will be realized when closer spacing is used.

When the sills were 2' long in the model (300' in prototype) and equally spaced around the bend, the space between the structures could be extended to 10 ft. in the model (1500' in prototype), and still maintain a channel with little or no tendency for large bars to develop in the channel. This length of sill reduced the channel width by 40 percent,

and resulted in an increased velocity in the unobstructed portion of the channel. The amount of scour off the ends of the longer structures was also increased.

The width of the unobstructed portion of the channel has a big influence on the degree of channel control. For a given length of sill a structure placed perpendicular to the flow will naturally encroach on the flow area to a greater degree than one placed at an angle. As a result more direct benefits per foot of structure are realized. Structures angled upstream did appear to have the ability to divert the water out toward the concave bank quite successfully, however the large amount of scour and attack on the ends of these structures and the possibility of water being directed toward the root of the structure could present major problems in the prototype.

When a large amount of water was allowed to pass over the structures, their effectiveness in diverting the water was greatly diminished. The model tests showed that when only 0.02 to 0.03' of water was allowed to pass over them ($\doteq$ 1 - 2' in river) they functioned quite satisfactorily. However, when flow depths exceeded 0.10' over the sills in the model (6' in river), the sills had little or no effect in diverting the flow. The amount of scour immediately downstream of the structures was also notably increased when the crest was lowered.

Tests performed in which the Q & d were increased to simulate flood flows did not appear to change the overall characteristics of the bend. Some of the fill material would probably be removed from behind the structures during these periods with additional scour on the downstream side, but no adverse effects were noted due to the presence of the sills.

It should be noted, however, that during such flows adequate navigation depths would be available while the capacity of the channel to contain flood discharges would not be effectively changed.

Sloping sills tend to reduce the amount of scour at the ends of the structures. The rate at which material builds up behind the structures was also increased. However, our tests indicated that the sloping sills were not quite as effective as level sills in their ability to divert the water toward the concave bank.

There appears to be definite advantages in a planned sequence of construction in a given bend. Tests in which structures were placed near the upstream portion of the bend first and using the new flow pattern as a guide for the location of the next structure, were very successful and resulted in less lineal footage of total structures. Locating sills in this manner is a matter of judgment, and model studies can greatly assist the engineer to achieve an optimum solution.

Tests in which both the length and the spacing varied also were satisfactory. Good results were obtained beginning with 200' sills at the entrance to the bend and gradually increasing this prototype length to 375' through the bend.

"L" shaped extensions on the ends of existing sills on the convex bank did not appear to assist the structures in diverting the flow. Extensions which were built parallel with the flow tended to keep the water concentrated next to them. Extensions which were placed at a downstream angle from the end of existing sills created currents behind the structure and reduced the accretion in this area. However, extensions did appear to reduce the scour around the ends of the sills.

Tests of existing conditions in Pomeroy Bend indicated that considerable improvement could be realized by extending dikes 404.7, 405.0, 406.0-B and 405.6 from the present 200' length to 300'. Very little benefit to the channel was noted when additional sills were installed between existing structures. Additional sills did result in more sediment accumulation along the convex bank.

The exact location and angle of an individual sill are largely determined by the angle of attack by the flow. Therefore the spacing, angle and length of an individual structure may vary at different locations in a bend depending upon how the stream lines are directed toward the structure. This angle may not only be different throughout a bend, but may be altered by time. A new structure with little or no accumulation of sediment behind and around it has a much different influence on the channel than one that has been in operation for a considerable length of time. This time differential may be the cause of certain reaches performing satisfactorily through one season but posing problems during following seasons.

POMEROY BEND MODEL STUDY
TABLE 3

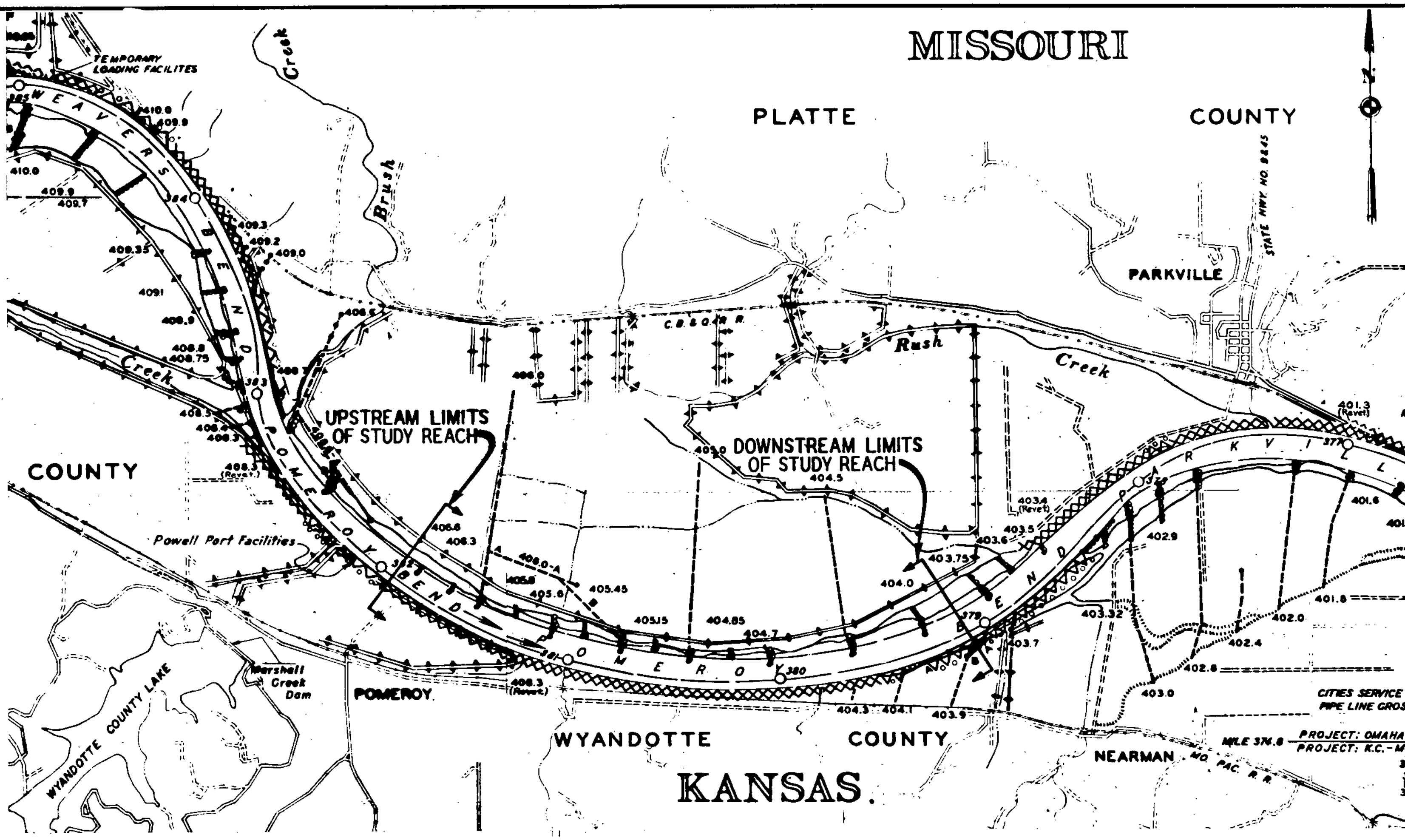
Run Number	Number of Sills	Sill Spacing Model ft	Sill Spacing Prototype ft	Length of Sills Model ft	Length of Sills Prototype ft	Crest of Sill	Water over Crest Model ft	Water over Crest Prototype ft	Angle of Sill to Flow
No River 1962		-	-	-	-	-	-	-	-
27B	None	-	-	-	-	-	-	-	-
Mo River 1965	9	Variable	Variable	1.33	200	Level	0.03	1.80	90°
28B	9	Variable	Variable	1.33	200	Level	0.03	1.80	90°
29A	1	100	15,000	1.33	200	Level	0.03	1.80	90°
29B	2	50	7,500	1.33	200	Level	0.03	1.80	90°
29C	5	20	3,000	1.33	200	Level	0.03	1.80	90°
29D	7	15	2,250	1.33	200	Level	0.03	1.80	90°
29E	10	10	1,500	1.33	200	Level	0.03	1.80	90°
29G	13	7.5	1,125	1.33	200	Level	0.03	1.80	90°
29F	20	5	750	1.33	200	Level	0.03	1.80	90°
30A	10	10	1,500	1.33	200	Level	0.03	1.80	75° up/s
30B	13	7.5	1,125	1.33	200	Level	0.03	1.80	75° up/s
30C	13	7.5	1,125	1.33	200	Level	0.03	1.80	60° up/s
30D	13	7.5	1,125	1.33	200	Level	0.10	6.00	60° up/s
30E	13	7.5	1,125	1.33	200	Level	0.03	1.80	75° d/s
30F	13	7.5	1,125	1.33	200	Sloping	0-0.10	0-6.00	90°
31A	5	20	3,000	2.00	300	Level	0.03	1.80	90°
31B	7	15	2,250	2.00	300	Level	0.03	1.80	90°
31C	10	10	1,500	2.00	300	Level	0.03	1.80	90°
31D	13	7.5	1,125	2.00	300	Level	0.03	1.80	90°

POMEROY BEND MODEL STUDY
TABLE 3 (Cont'd)

Run Number	Number of Sills	Sill Spacing Model ft	Sill Spacing Prototype ft	Length of Sills Model ft	Length of Sills Prototype ft	Crest of Sill	Water over Crest Model ft	Water over Crest Prototype ft	Angle of Sill to Flow
32A	1	Variable	Variable	2.00	300	Level	0.03	1.80	90°
32B	2	Variable	Variable	2.00	300	Level	0.03	1.80	90°
32C	3	Variable	Variable	2.00	300	Level	0.03	1.80	90°
32D	4	Variable	Variable	2.00	300	Level	0.03	1.80	90°
32E	5	Variable	Variable	2.00	300	Level	0.03	1.80	90°
32F	6	Variable	Variable	2.00	300	Level	0.03	1.80	90°
32G	7	Variable	Variable	2.00	300	Level	0.03	1.80	90°
33A	3	Variable	Variable	2.00	300	Sloping	0-0.10	0-6.00	90°
33B	4	Variable	Variable	2.00	300	Sloping	0-0.10	0-6.00	90°
33C	6	Variable	Variable	2.00	300	Sloping	0-0.10	0-6.00	90°
34A	3	Variable	Variable	2.00	300	Sloping	0-0.20	0-12.0	90°
34B	4	Variable	Variable	2.00	300	Sloping	0-0.20	0-12.0	90°
34C	5	Variable	Variable	2.00	300	Sloping	0-0.20	0-12.0	90°
34D	7	Variable	Variable	2.00	300	Sloping	0-0.20	0-12.0	90°
35A2	9	Variable	Variable	1.33	200	Level	0.03	1.80	90°
35B2	10	Variable	Variable	1.33	200	Level	0.03	1.80	90°
36A	9	Variable	Variable	Variable	Variable	Level	0.03	1.80	90°
36A1	9	Variable	Variable	Variable	Variable	Level	0.03	1.80	90°
36B	9	Variable	Variable	6 @ 1.33 3 @ 2.00	6 @ 200 3 @ 300	Level	0.03	1.80	90°
36D	9	Variable	Variable	4 @ 1.33 5 @ 2.00	4 @ 200 5 @ 300	Level	0.03	1.80	90°
36E	9	Variable	Variable	4 @ 1.33 + 0.67" L Head	4 @ 300	Level	0.03	1.80	L Heads @ 60° d/s
				5 @ 1.33	5 @ 200	Level	0.03	1.80	Mail Sills @ 90°

POMEROY BEND MODEL STUDY
TABLE 3 (Cont'd)

Run Number	Number of Sills	Sill Spacing Model ft	Sill Spacing Prototype ft	Length of Sills Model ft	Length of Sills Prototype ft	Crest of Sill	Model ft	Prototype ft	Angle of Sill to Flow
36F	9	Variable	Variable	4 @ 1.33 + 0.67' ext.	300	Level	0.03	1.80	Main Sills @ 90° Extensions @ 0°
				5 @ 1.33	200	Level	0.03	1.80	90°
37A	1	Variable	Variable	1.33	200	Level	0.03	1.80	90°
37B	2	Variable	Variable	1 @ 1.33	200	Level	0.03	1.80	90°
				1 @ 2.00	300	Level	0.03	1.80	90°
37C	3	Variable	Variable	1 @ 1.33	200	Level	0.03	1.80	90°
				2 @ 2.00	300	Level	0.03	1.80	90°
37D	4	Variable	Variable	1 @ 1.33	200	Level	0.03	1.80	90°
				3 @ 2.00	300	Level	0.03	1.80	90°
37E	5	Variable	Variable	1 @ 1.33	200	Level	0.03	1.80	90°
				4 @ 2.00	300	Level	0.03	1.80	90°
37F	6	Variable	Variable	1 @ 1.33	200	Level	0.03	1.80	90°
				5 @ 2.00	300	Level	0.03	1.80	90°
38A	1	Variable	Variable	1 @ 2.00	300	Sloping	0-0.10	0- 6.0	90°
38B	2	Variable	Variable	2 @ 2.00	300	Sloping	0-0.10	0- 6.0	90°
38C	4	Variable	Variable	2 @ 2.00	300	Sloping	0-0.10	0- 6.0	90°
				2 @ 2.50	375	Sloping	0-0.10	0- 6.0	90°
38D	6	Variable	Variable	3 @ 2.00	300	Sloping	0-0.10	0- 6.0	90°
				3 @ 2.50	375	Sloping	0-0.10	0- 6.0	90°
39A	9	Variable	Variable	1 @ 2.0	300				90°
				2 @ 1.33 + 1.00 ext.	450	Level	0.03	1.80	Main Sill @ 90° Extension @ 0°
				6 @ 1.33	200	Level	0.03	1.80	90°
39B	9	Variable	Variable	1 @ 2.0	300	Level	0.03	1.80	90°
				2 @ 1.33 + 1.0 ext.	450	Level	0.03	1.80	Main Sill @ 90° Extension @ 60° d/s
				6 @ 1.33	200	Level	0.03	1.80	90°



LEGEND
(RIVER IMPROVEMENTS)

PILE DIKE W/TERMINAL
ROCK FILLED DIKE
PILE DIKE W/ROCK FILL
PILE REVETMENT
PILE REVETMENT W/SCREEN PILES
PILE REVETMENT W/SUSPENDED MATTRESS
PILE REVETMENT W/ROCK FILL
STANDARD REVETMENT
ABATIS
RETARD
PROPOSED STABILIZED CHANNEL LINE

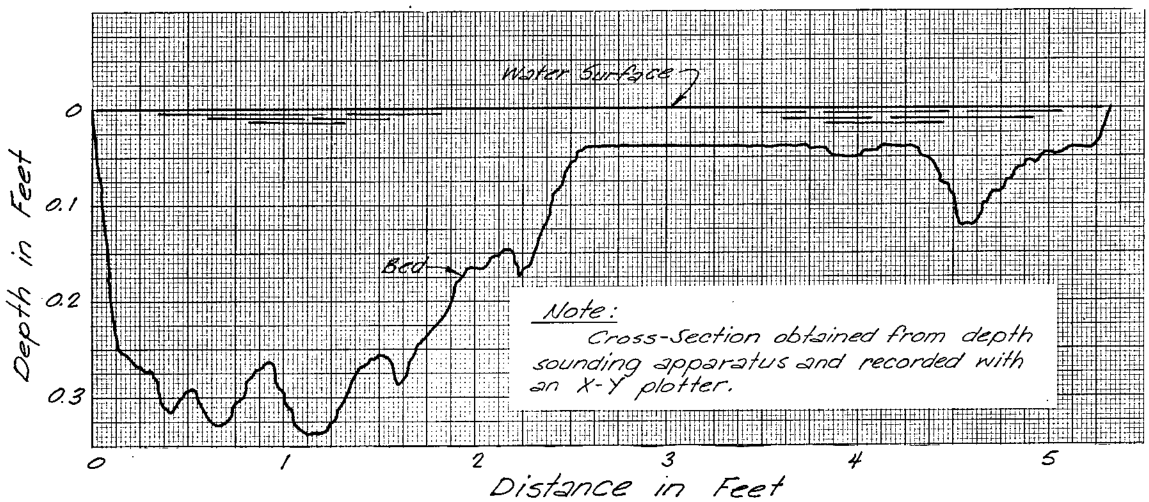
MILES ABOVE MOUTH (1960 ADJUSTMENT) 249

1000 0 1000 2000 3000 4000 5000
SCALE IN FEET

MISSOURI RIVER DESIGN STUDY
POMEROY BEND STUDY REACH

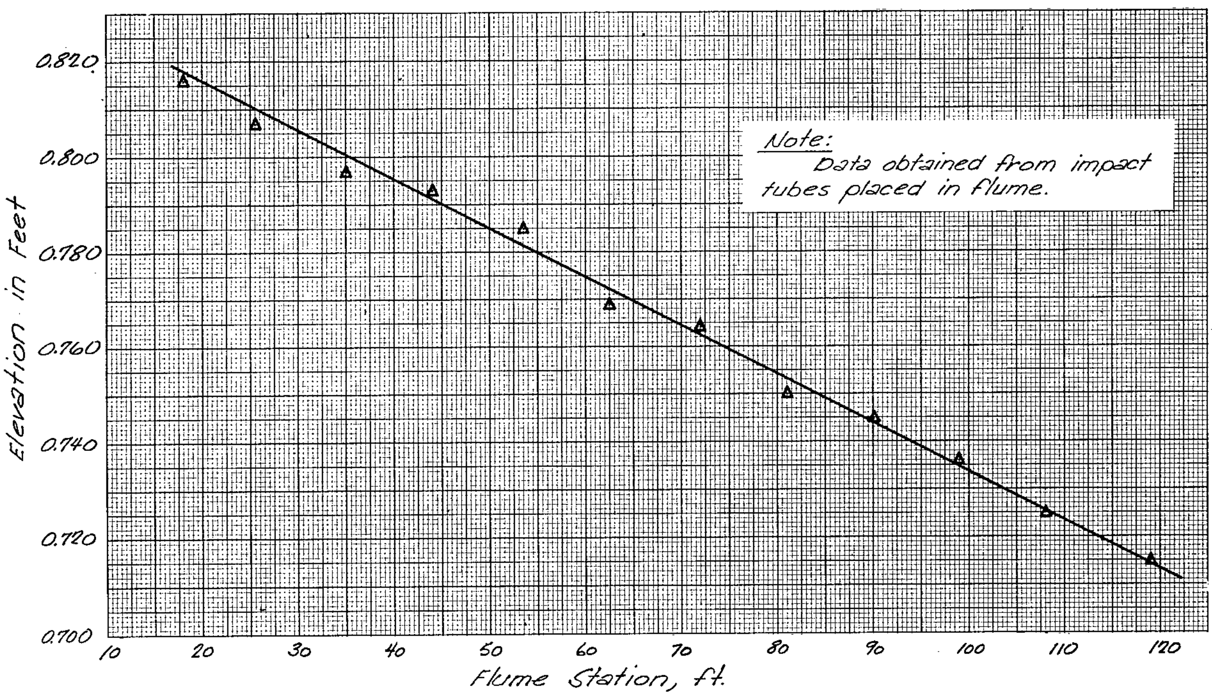
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
NOVEMBER 1966

PLATE 1



TYPICAL CROSS SECTION

STATION 44.1 - RUN 34-D



TYPICAL ENERGY SLOPE PROFILE

MISSOURI RIVER DESIGN STUDY
POMEROY BEND

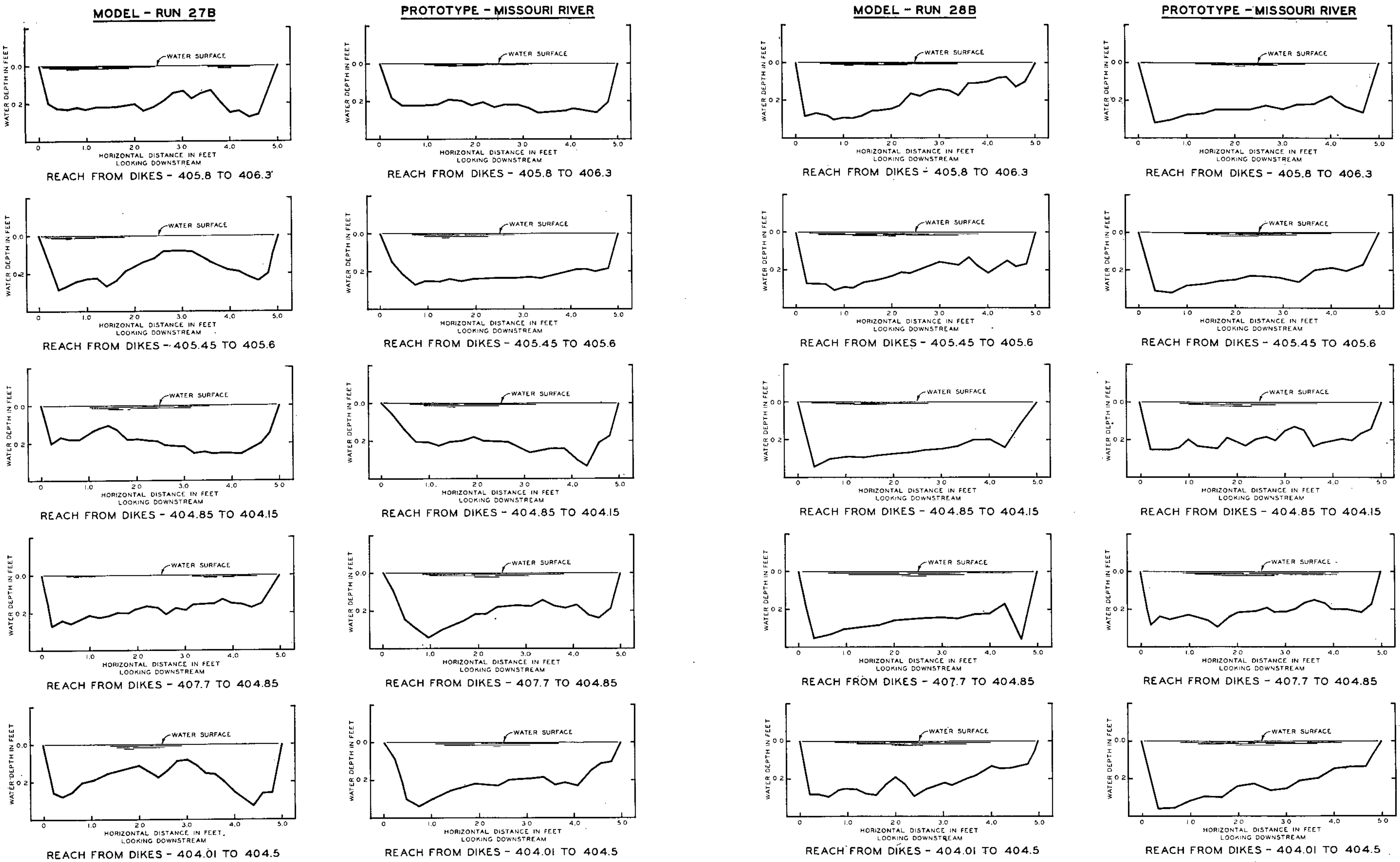
SAMPLE DATA

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA

NOVEMBER 1966

BEFORE SILL CONSTRUCTION

AFTER SILL CONSTRUCTION

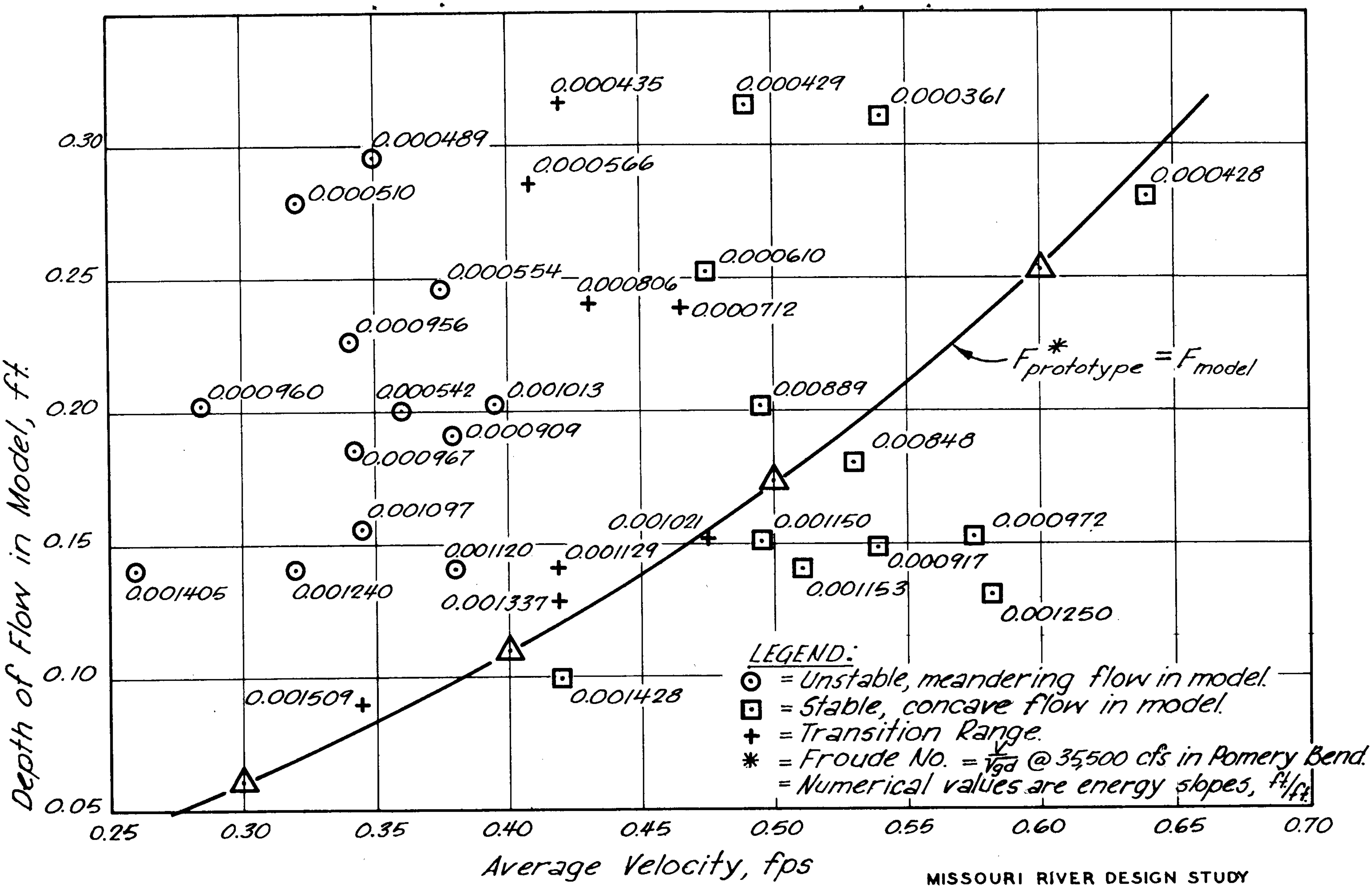


MISSOURI RIVER DESIGN STUDY
POMEROY BEND

AVERAGE CROSS SECTION

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
NOVEMBER 1966

PLATE 3



MISSOURI RIVER DESIGN STUDY
POMEROY BEND

DEPTH-VELOCITY RELATIONSHIPS IN MODEL
FOR THREE TYPES OF FLOW

NOVEMBER 1966 **PLATE 4**

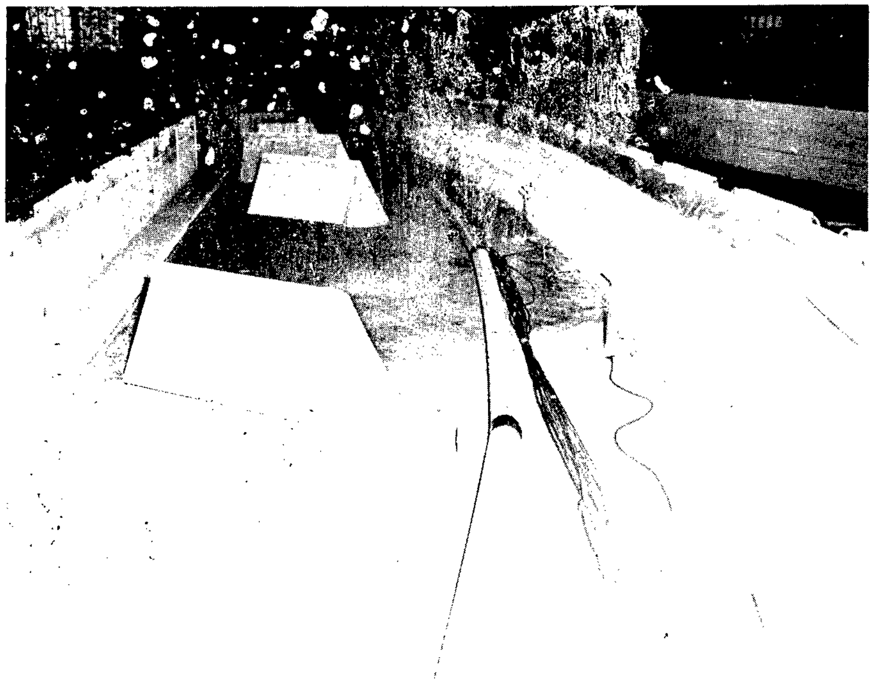


FIG. 1 VIEW OF FLUME SHOWING INSTALLATION OF DIKES, DRAIN PIPE AND IMPACT TUBES

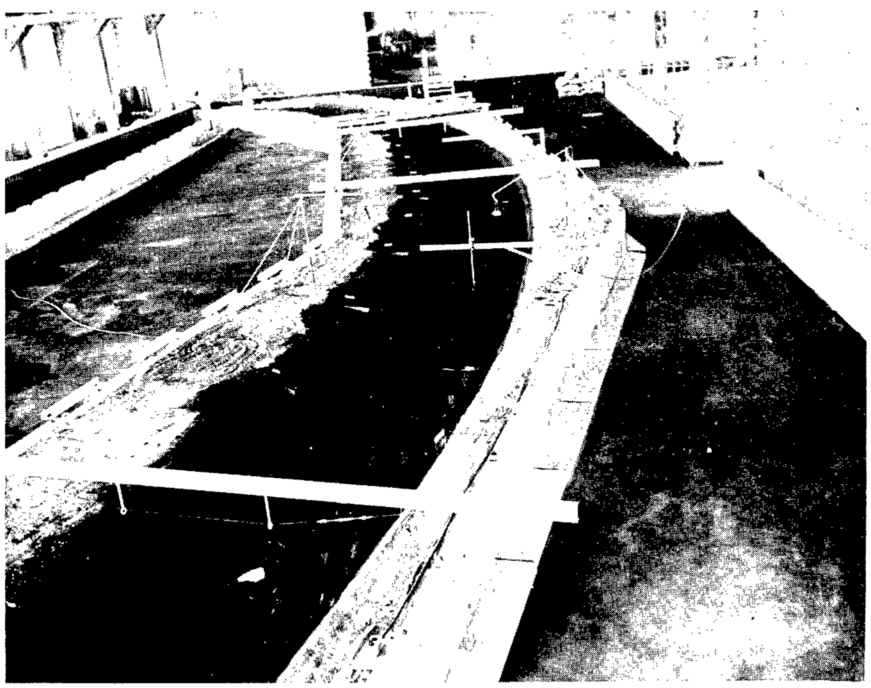


FIG. 2 TYPICAL BED FORMATION AT THE COMPLETION OF A TEST

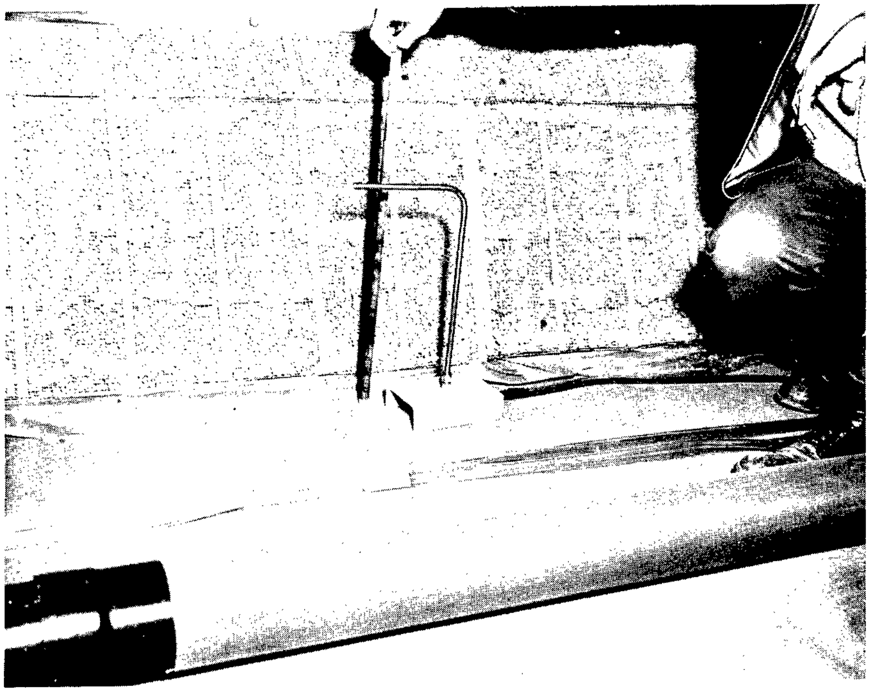


FIG. 3 IMPACT TUBES SPACED AT 10' INTERVALS USED TO RECORD ENERGY GRADIENT

FIG. 4 CROSS SECTION AT THE COMPLETION OF A TEST RUN

FIG. 5 FLOW PATTERN AROUND A SPUR DIKE. FLOW IS FROM LEFT TO RIGHT

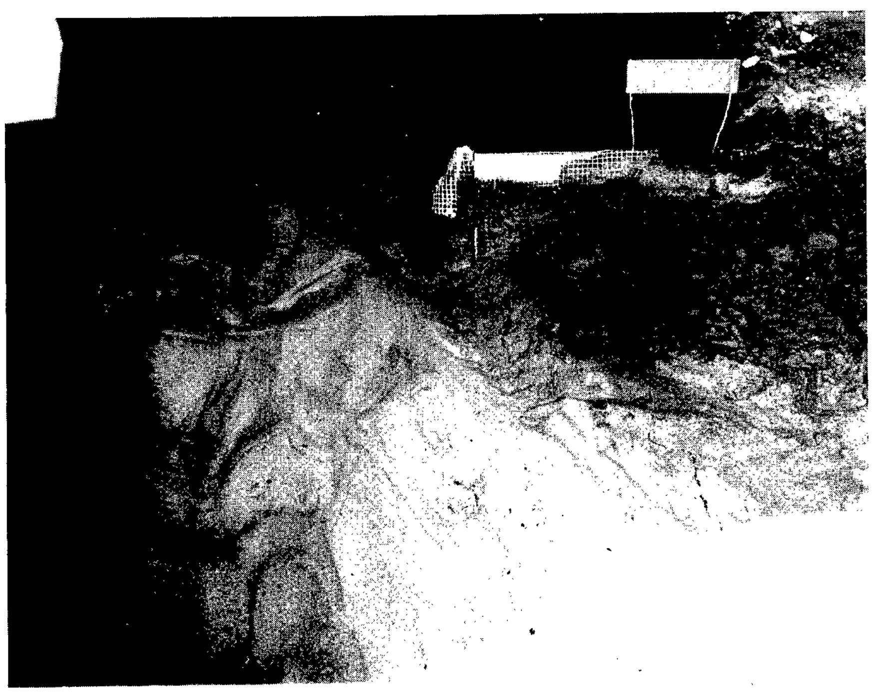


FIG. 6 BED FORMATION AROUND SPUR DIKE AT THE COMPLETION OF A TEST

FIG. 7 ADJUSTABLE SILL. ELEVATION OF SILL IS CHANGED BY TURNING THREADED ROD

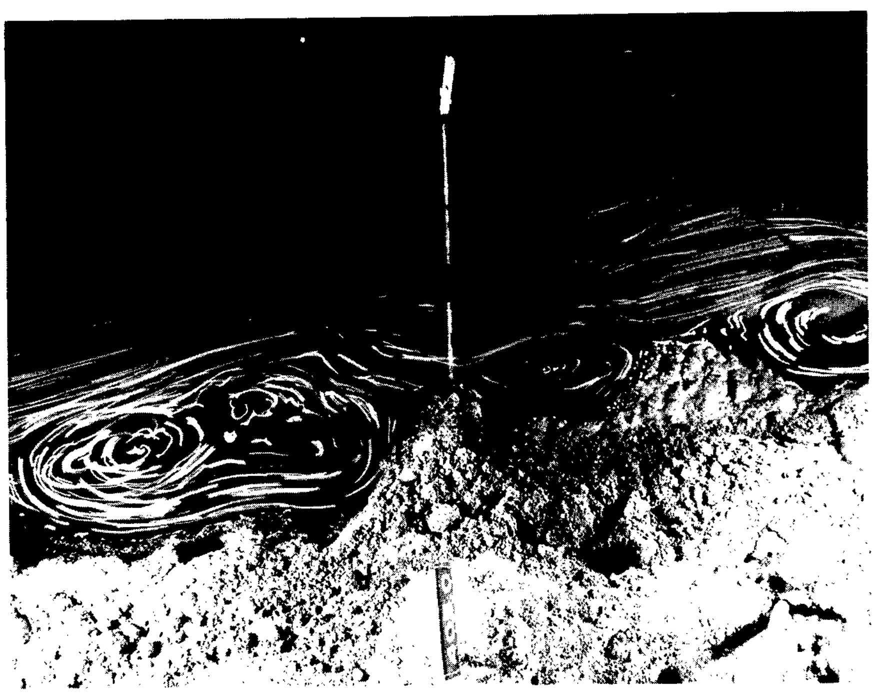
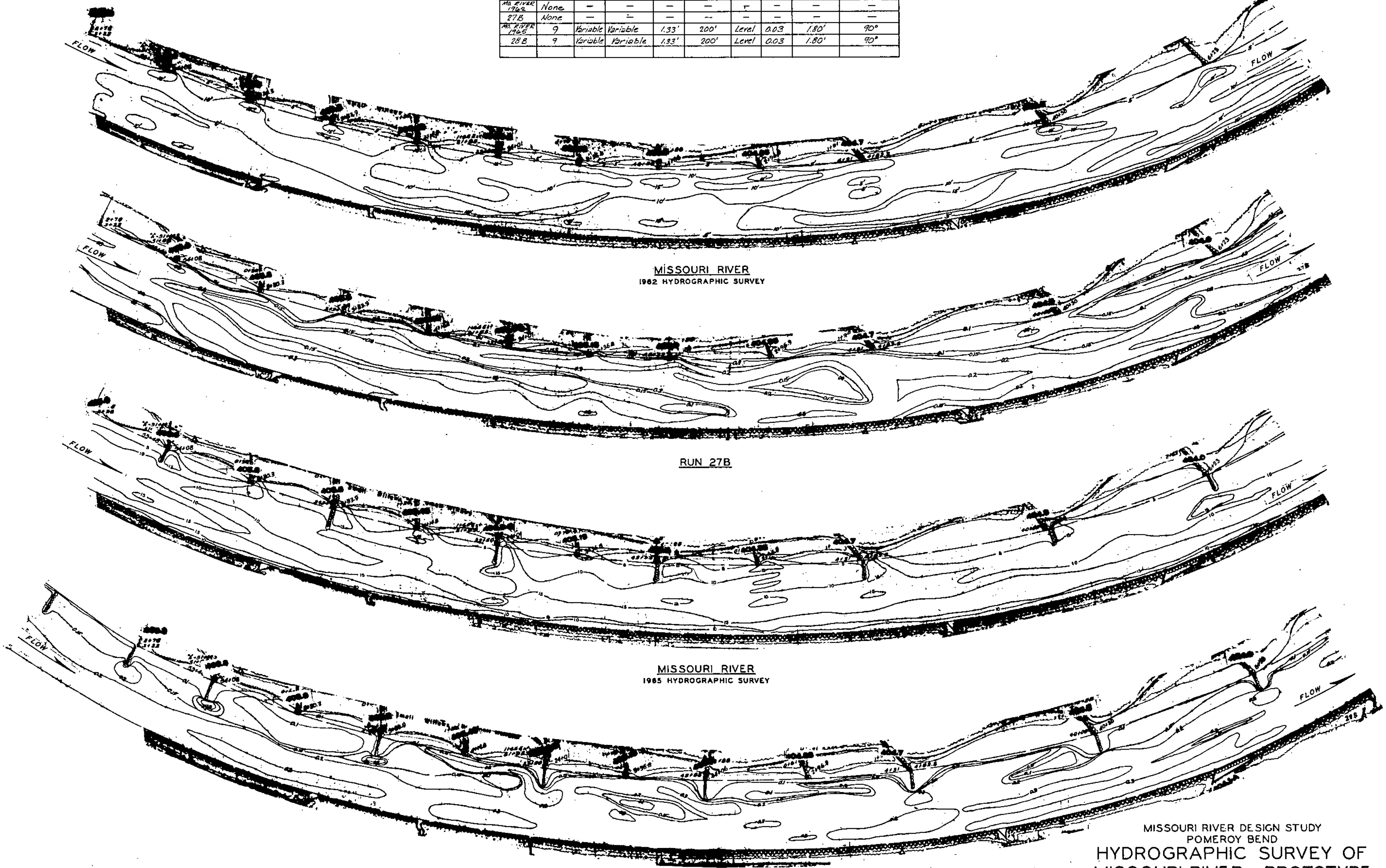


FIG. 8 FLOW PATTERN OVER AN UNDERWATER SILL. FLOW IS FROM LEFT TO RIGHT

TEST INDEX									
RUN NUMBER	NUMBER OF SILLS	SILL SPACING, FT		LENGTH OF SILLS, FT		CREST OF SILL	WATER OVER CREST, FT		ANGLE OF SILL TO FLOW
		MODEL	PROTOTYPE	MODEL	PROTOTYPE		MODEL	PROTOTYPE	
Mo. RIVER 1962	None	—	—	—	—	—	—	—	—
27B	None	—	—	—	—	—	—	—	—
Mo. RIVER 1965	9	Variable	Variable	1.33'	200'	Level	0.03	1.80'	90°
28B	9	Variable	Variable	1.33'	200'	Level	0.03	1.80'	90°



MISSOURI RIVER
1962 HYDROGRAPHIC SURVEY

RUN 27B

MISSOURI RIVER
1965 HYDROGRAPHIC SURVEY

RUN 28B

PROTOTYPE - SCALE IN FEET
400 0 400 800 1200

MODEL - SCALE IN FEET
5 0 5 10

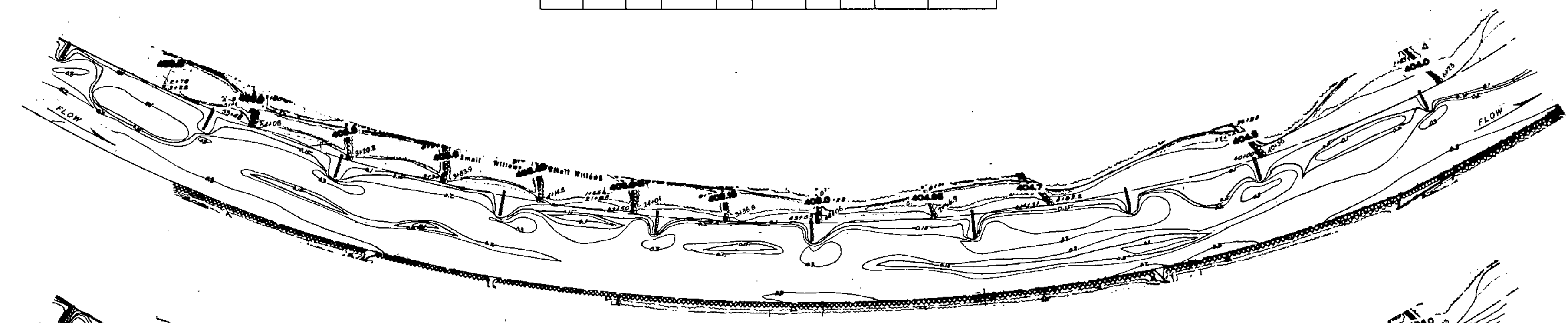
MISSOURI RIVER DESIGN STUDY
POMEROY BEND

HYDROGRAPHIC SURVEY OF MISSOURI RIVER – PROTOTYPE AND TEST SERIES 27 & 28

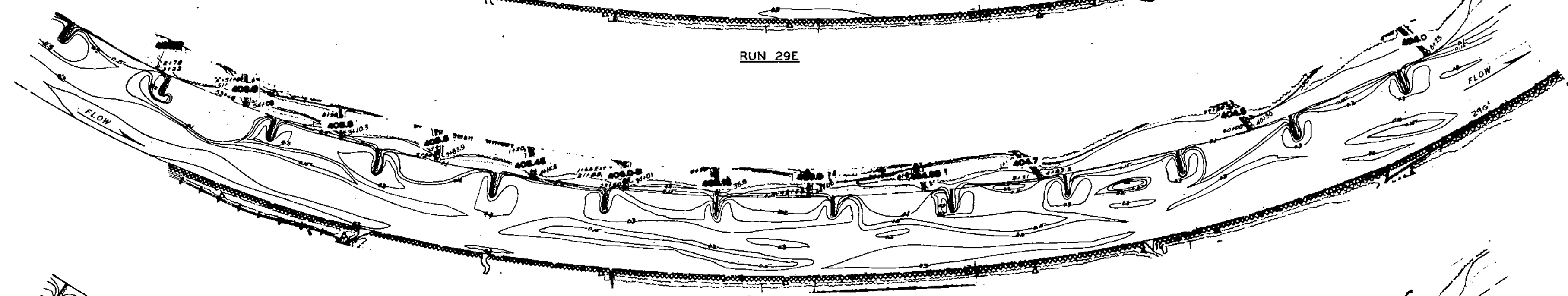
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
NOVEMBER 1966

RUN NUMBER	NUMBER OF SILLS	SILL SPACING, FT MODEL	SILL SPACING, FT PROTOTYPE	LENGTH OF SILLS, FT MODEL	LENGTH OF SILLS, FT PROTOTYPE	CREST OF SILL	WATER OVER CREST, FT MODEL	WATER OVER CREST, FT PROTOTYPE	ANGLE OF SILL TO FLOW
29E	10	10'	1,500'	1.33'	200'	Level	0.03	1.80'	90°
29G	13	7.5'	1125'	1.33'	200'	Level	0.03	1.80'	90°
29F	20	5'	750'	1.33'	200'	Level	0.03	1.80'	90°

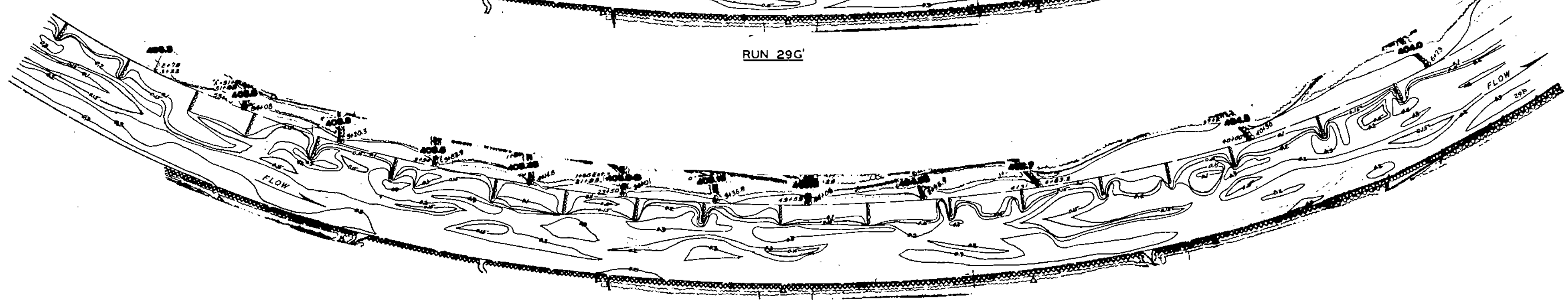
TEST INDEX



RUN 29E



RUN 29G'



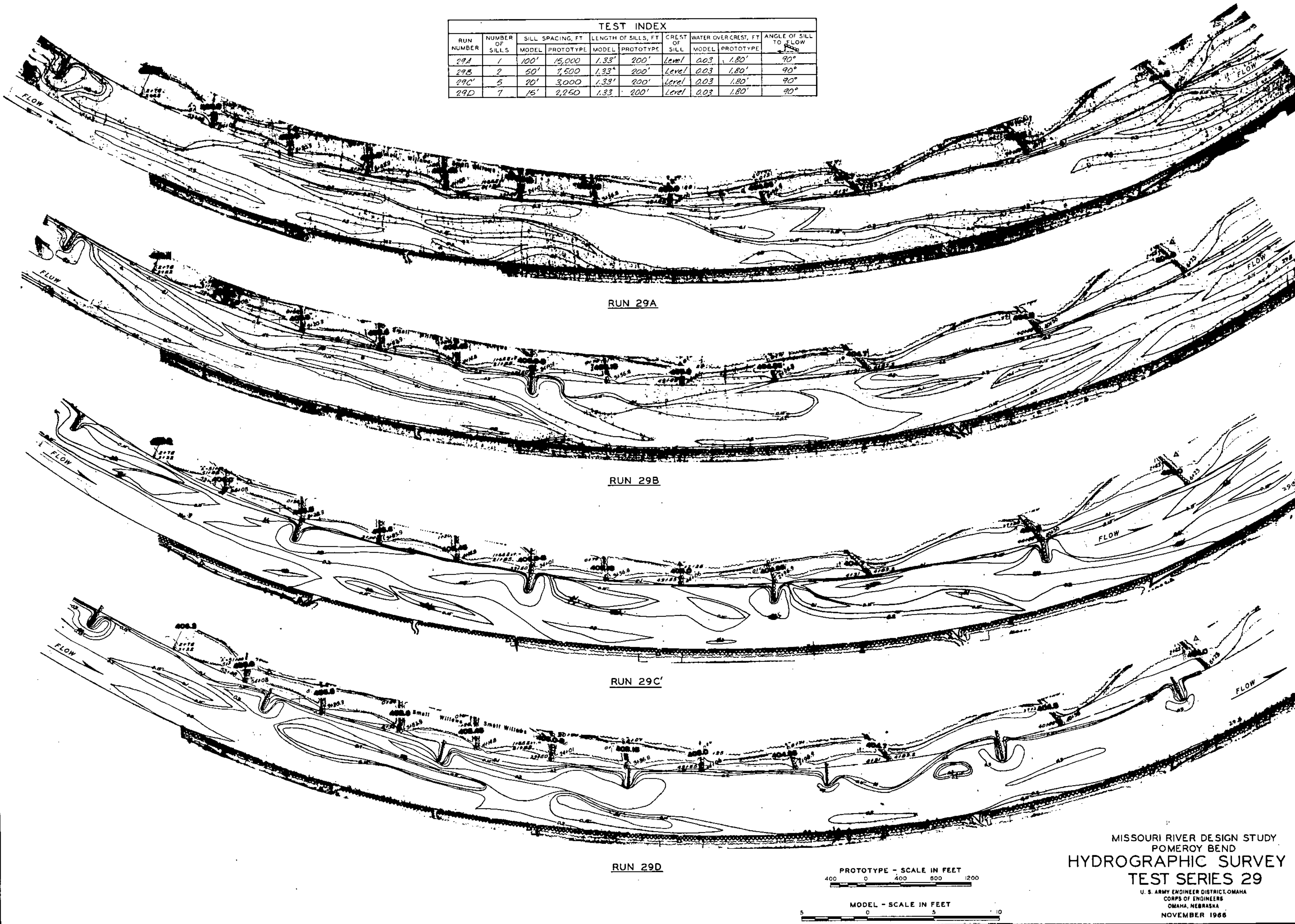
RUN 29F

PROTOTYPE - SCALE IN FEET
400 0 400 800 1200

MODEL - SCALE IN FEET
5 0 5 10

MISSOURI RIVER DESIGN STUDY
POMEROY BEND
HYDROGRAPHIC SURVEY OF
TEST SERIES 29
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
NOVEMBER 1966

TEST INDEX									
RUN NUMBER	NUMBER OF SILLS	SILL SPACING, FT		LENGTH OF SILLS, FT		CREST OF SILL	WATER OVER CREST, FT		ANGLE OF SILL TO FLOW
		MODEL	PROTOTYPE	MODEL	PROTOTYPE		MODEL	PROTOTYPE	
29A	1	100'	15,000	1.33'	200'	Level	0.03	1.80'	90°
29B	2	50'	7,500	1.33'	200'	Level	0.03	1.80'	90°
29C'	5	20'	3,000	1.33'	200'	Level	0.03	1.80'	90°
29D	7	15'	2,250	1.33	200'	Level	0.03	1.80'	90°

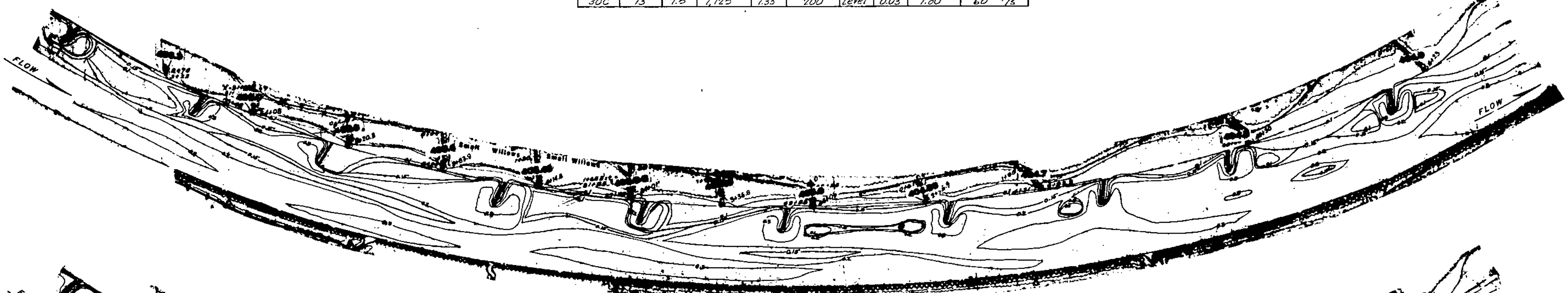


MISSOURI RIVER DESIGN STUDY
POMEROY BEND

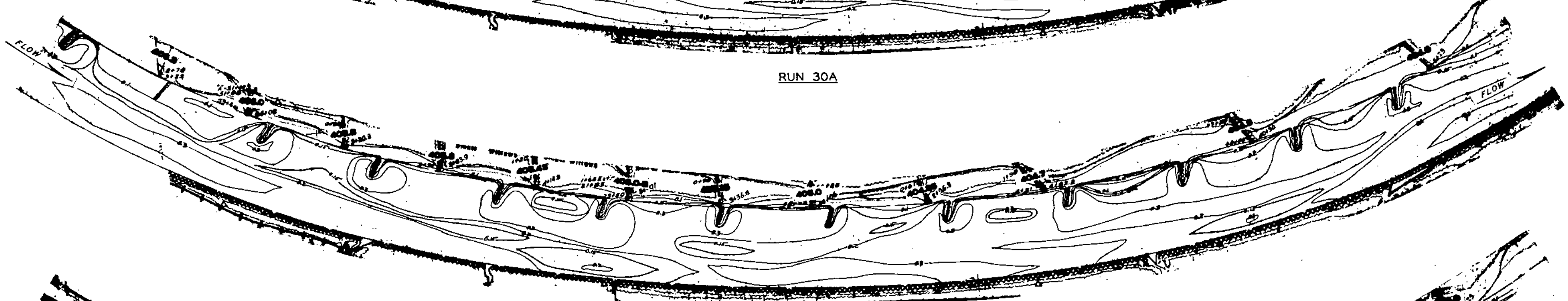
HYDROGRAPHIC SURVEY OF TEST SERIES 29

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
NOVEMBER 1966

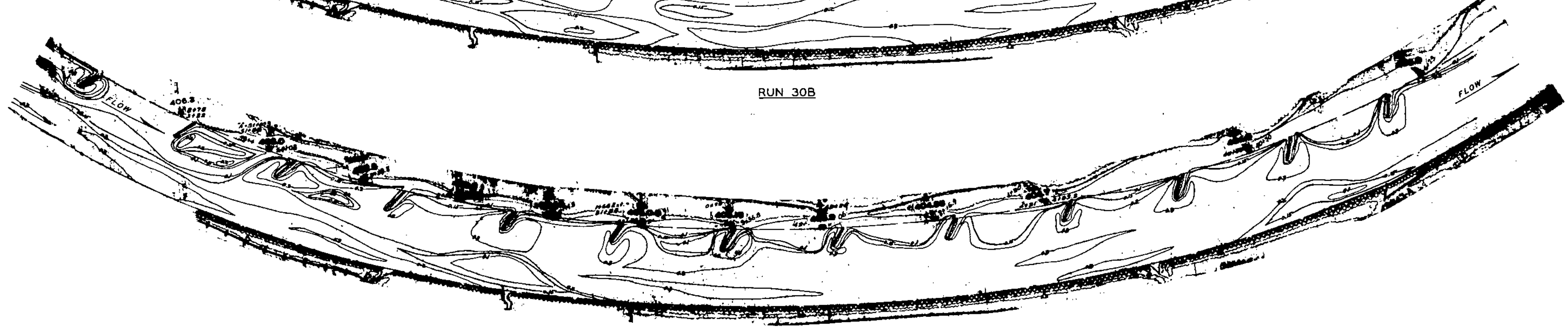
TEST INDEX									
RUN NUMBER	NUMBER OF SILLS	SILL SPACING, FT		LENGTH OF SILLS, FT		CREST OF SILL	WATER OVER CREST, FT		ANGLE OF SILL TO FLOW
		MODEL	PROTOTYPE	MODEL	PROTOTYPE		MODEL	PROTOTYPE	
30A	10	10'	1,500'	1.33'	200'	Level	0.03	1.80'	75° up/s
30B	13	7.5'	1,125'	1.33'	200'	level	0.03	1.80'	75° up/s
30C	13	7.5'	1,125'	1.33'	200'	level	0.03	1.80'	60° up/s



RUN 30A



RUN 30B



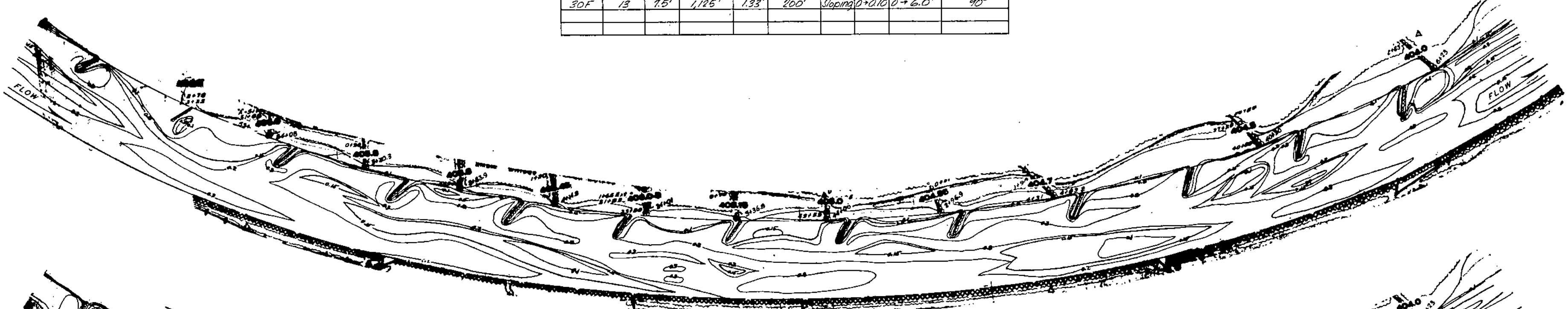
RUN 30C

PROTOTYPE - SCALE IN FEET
400 0 400 800 1200

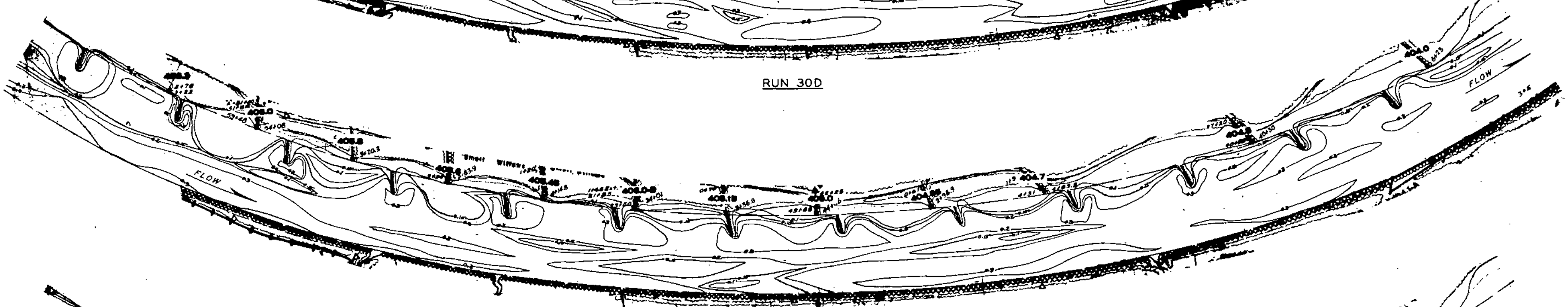
MODEL - SCALE IN FEET
5 0 5 10

MISSOURI RIVER DESIGN STUDY
POMEROY BEND
HYDROGRAPHIC SURVEY OF
TEST SERIES 30
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
NOVEMBER 1966

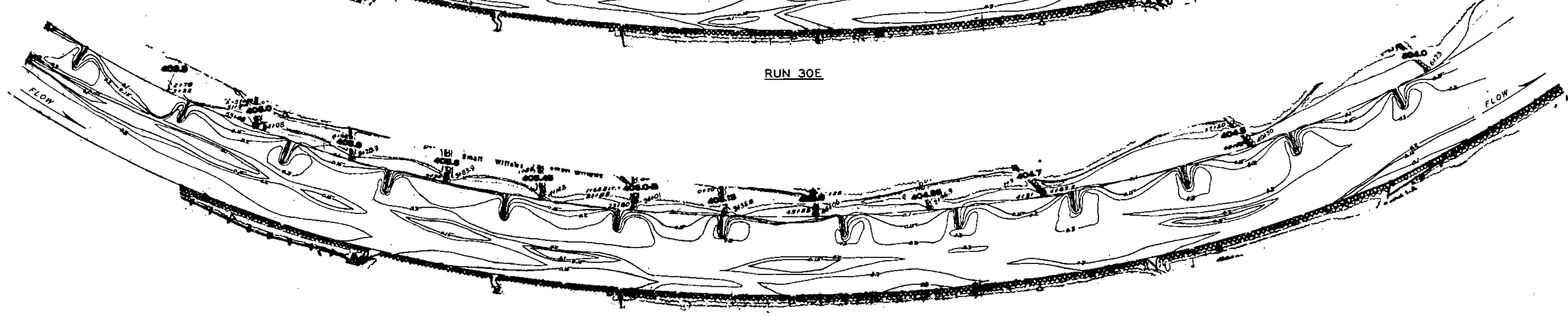
TEST INDEX									
RUN NUMBER	NUMBER OF SILLS	SILL SPACING, FT		LENGTH OF SILLS, FT		CREST OF SILL	WATER OVER CREST, FT		ANGLE OF SILL TO FLOW
		MODEL	PROTOTYPE	MODEL	PROTOTYPE		MODEL	PROTOTYPE	
30D	13	7.5'	1,125'	1.33'	200'	Level	0.10'	6.00'	60° u/s
30E	13	7.5'	1,125'	1.33'	200'	Level	0.03'	1.80'	75° d/s
30F	13	7.5'	1,125'	1.33'	200'	Sloping	0→0.10	0→6.0'	90°



RUN 30D



RUN 30E



RUN 30F

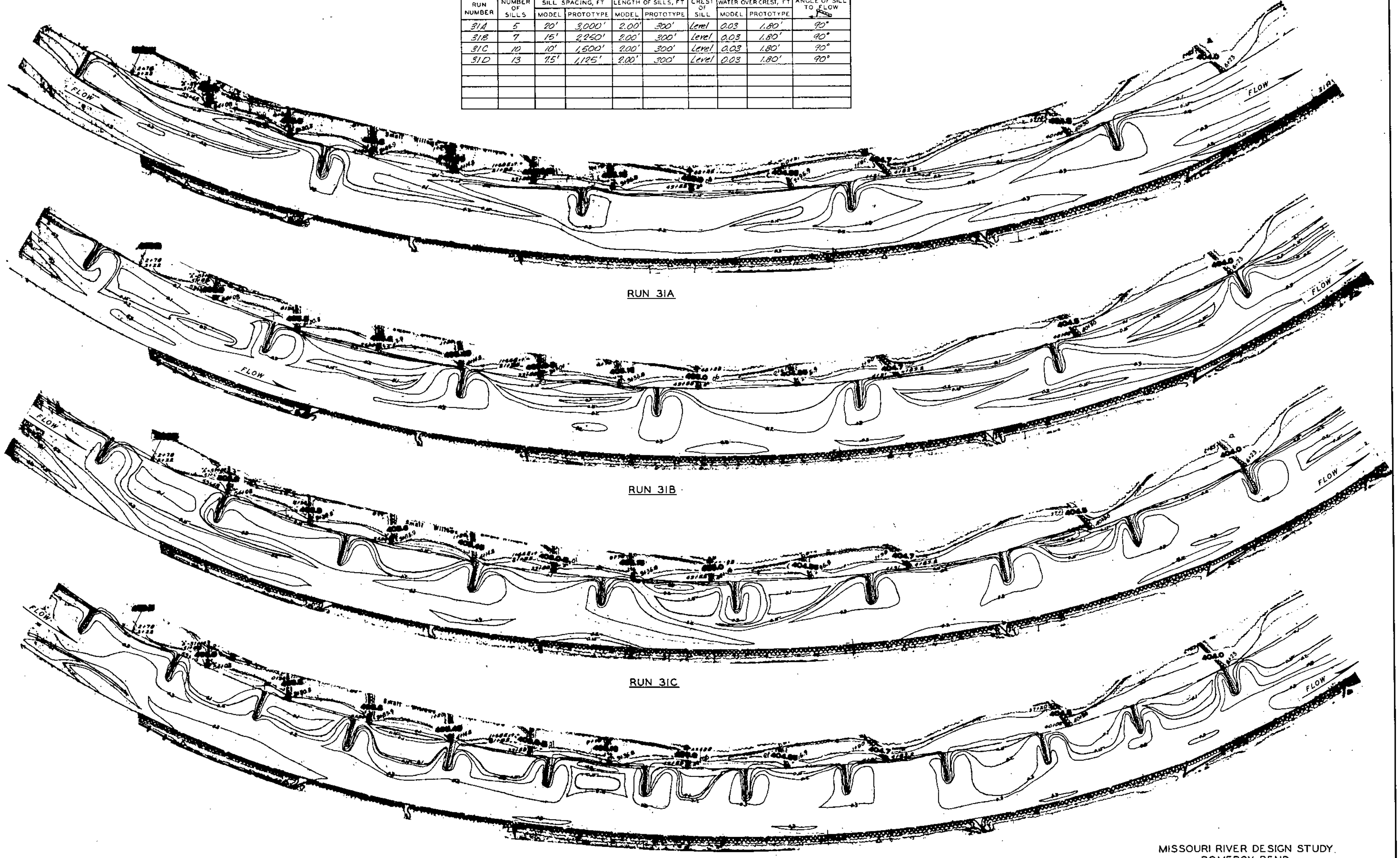
PROTOTYPE - SCALE IN FEET
400 0 400 800 1200

MODEL - SCALE IN FEET
5 0 5 10

MISSOURI RIVER DESIGN STUDY
POMEROY BEND
HYDROGRAPHIC SURVEY OF
TEST SERIES 30

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
NOVEMBER 1986

TEST INDEX									
RUN NUMBER	NUMBER OF SILLS	SILL SPACING, FT		LENGTH OF SILLS, FT		CREST OF SILL	WATER OVER CREST, FT		ANGLE OF SILL TO FLOW
		MODEL	PROTOTYPE	MODEL	PROTOTYPE		MODEL	PROTOTYPE	
31A	5	20'	3,000'	2.00'	300'	Level	0.03	1.80'	90°
31B	7	15'	2,250'	2.00'	300'	Level	0.03	1.80'	90°
31C	10	10'	1,500'	2.00'	300'	Level	0.03	1.80'	90°
31D	13	7.5'	1,125'	2.00'	300'	Level	0.03	1.80'	90°

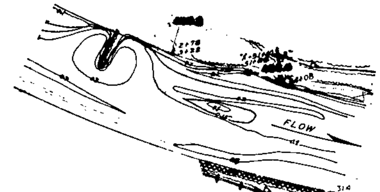


PROTOTYPE - SCALE IN FEET
400 0 400 800 1200

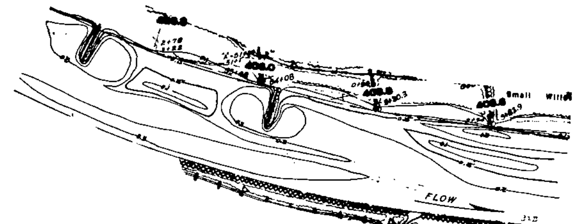
MODEL - SCALE IN FEET
5 0 5 10

MISSOURI RIVER DESIGN STUDY
POMEROY BEND
HYDROGRAPHIC SURVEY OF TEST SERIES 31
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
NOVEMBER 1966

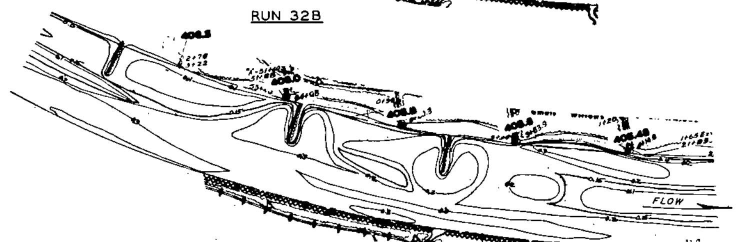
TEST INDEX									
RUN NUMBER	NUMBER OF SILLS	SILL SPACING, FT		LENGTH OF SILLS, FT		CREST OF SILL	WATER OVER CREST, FT		ANGLE OF SILL TO FLOW
		MODEL	PROTOTYPE	MODEL	PROTOTYPE		MODEL	PROTOTYPE	
32A	1	Variable	Variable	2.00'	300'	Level	0.03'	1.80'	90°
32B	2	"	"	2.00'	300'	Level	0.03'	1.80'	90°
32C	3	"	"	2.00'	300'	Level	0.03'	1.80'	90°
32D	4	"	"	2.00'	300'	Level	0.03'	1.80'	90°
32E	5	"	"	2.00'	300'	Level	0.03'	1.80'	90°
32F	6	"	"	2.00'	300'	Level	0.03'	1.80'	90°
32G	7	Variable	Variable	2.00'	300'	Level	0.03'	1.80'	90°



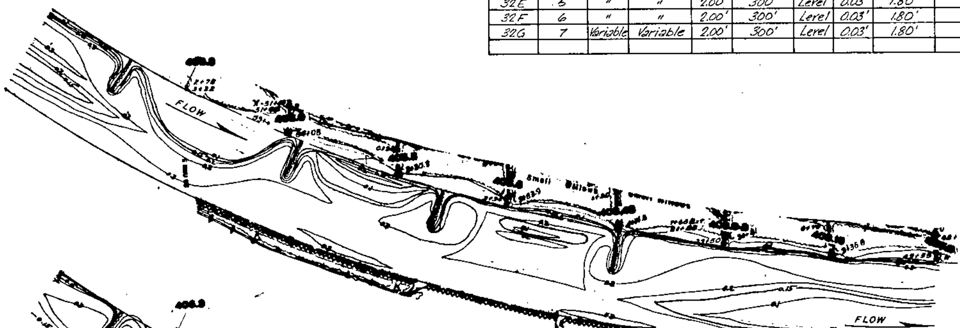
RUN 32A



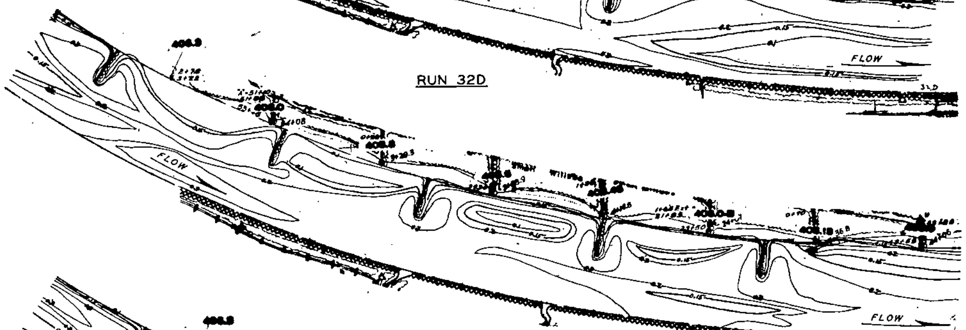
RUN 32B



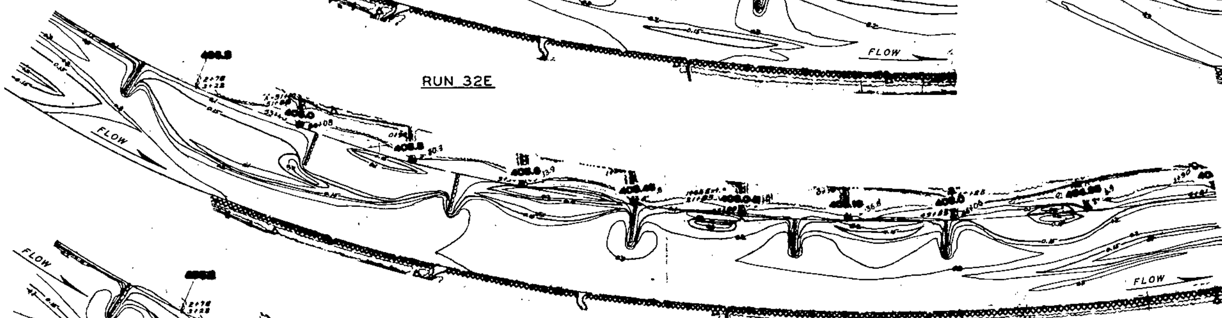
RUN 32C



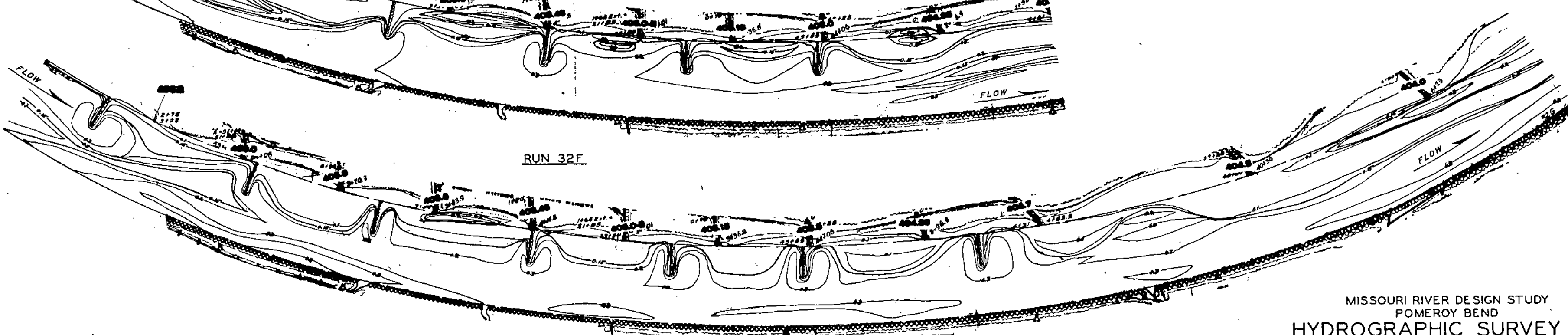
RUN 32D



RUN 32E



RUN 32F



RUN 32G

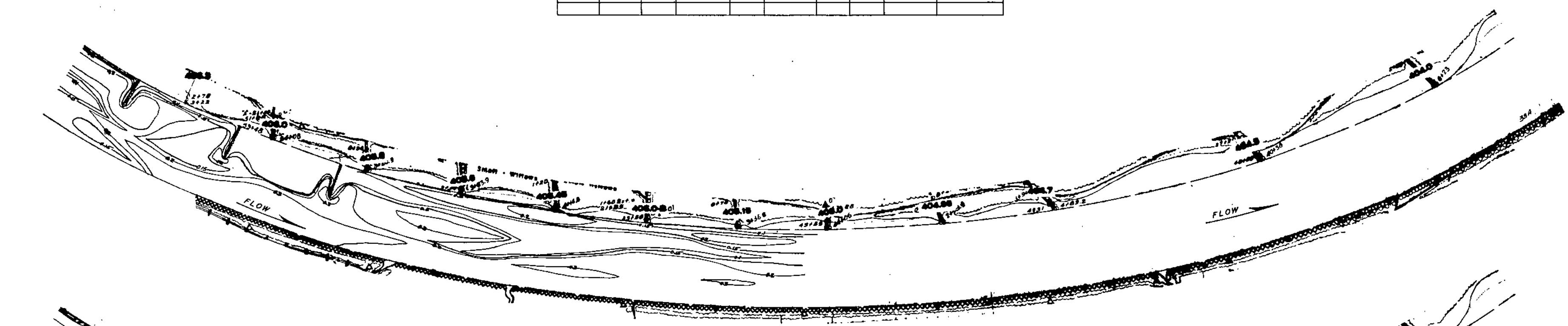
PROTOTYPE - SCALE IN FEET
400 0 400 800 1200

MODEL - SCALE IN FEET
5 0 5 10

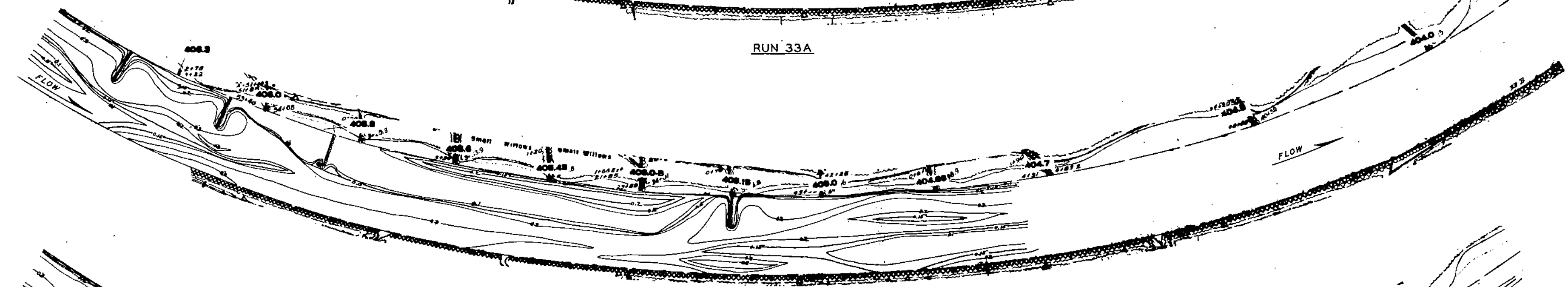
MISSOURI RIVER DESIGN STUDY
POMEROY BEND
HYDROGRAPHIC SURVEY OF TEST SERIES 32

U S ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
NOVEMBER 1966

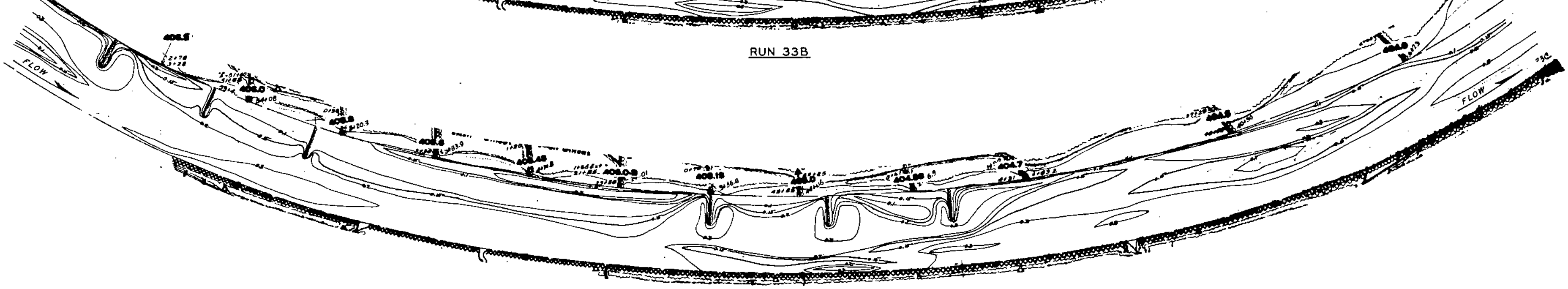
TEST INDEX									
RUN NUMBER	NUMBER OF SILLS	SILL SPACING, FT		LENGTH OF SILLS, FT		CREST OF SILL	WATER OVER CREST, FT		ANGLE OF SILL TO FLOW
		MODEL	PROTOTYPE	MODEL	PROTOTYPE		MODEL	PROTOTYPE	
33A	3	Variable	Variable	2.00'	300'	Sloping	0-0.10'	0-6.00'	90°
33B	4	Variable	Variable	2.00'	300'	Sloping	0-0.10'	0-6.00'	90°
33C	6	Variable	Variable	2.00'	300'	Sloping	0-0.10'	0-6.00'	90°



RUN 33A



RUN 33B

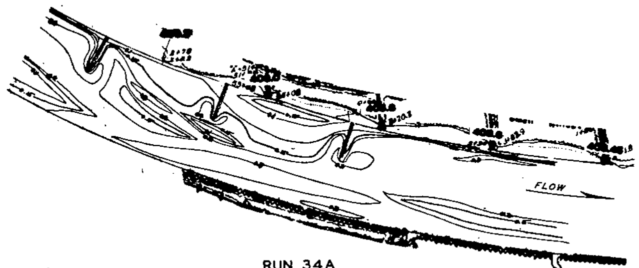


RUN 33C

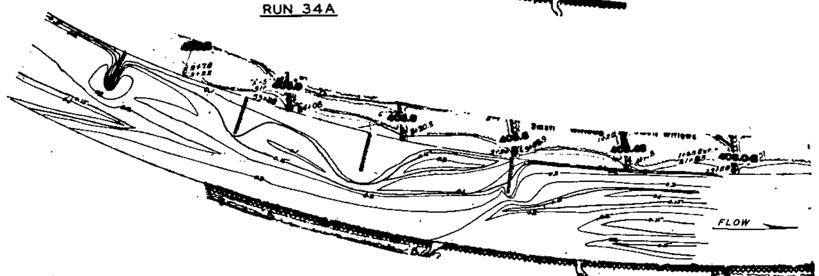
PROTOTYPE - SCALE IN FEET
400 0 400 800 1200

MODEL - SCALE IN FEET
5 0 5 10

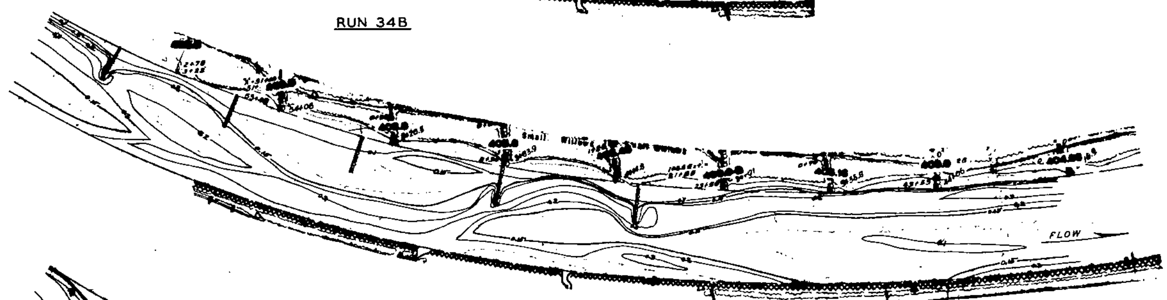
MISSOURI RIVER DESIGN STUDY
POMEROY BEND
HYDROGRAPHIC SURVEY OF TEST SERIES 33
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
NOVEMBER 1966



RUN 34A



RUN 34B



RUN 34C

RUN 34D

TEST INDEX

RUN NUMBER	NUMBER OF SILLS	SILL SPACING, FT MODEL	SILL SPACING, FT PROTOTYPE	LENGTH OF SILLS, FT MODEL	LENGTH OF SILLS, FT PROTOTYPE	CREST OF SILL	WATER OVER CREST, FT MODEL	WATER OVER CREST, FT PROTOTYPE	ANGLE OF SILL TO FLOW
34A	3	Variable	Variable	2.00'	300'	Sloping	0→0.20	0→12.0'	90°
34B	4	"	"	2.00'	300'	Sloping	0→0.20'	0→12.0'	90°
34C	5	"	"	2.00'	300'	Sloping	0→0.20'	0→12.0'	90°
34D	7	Variable	Variable	2.00'	300'	Sloping	0→0.20'	0→12.0'	90°

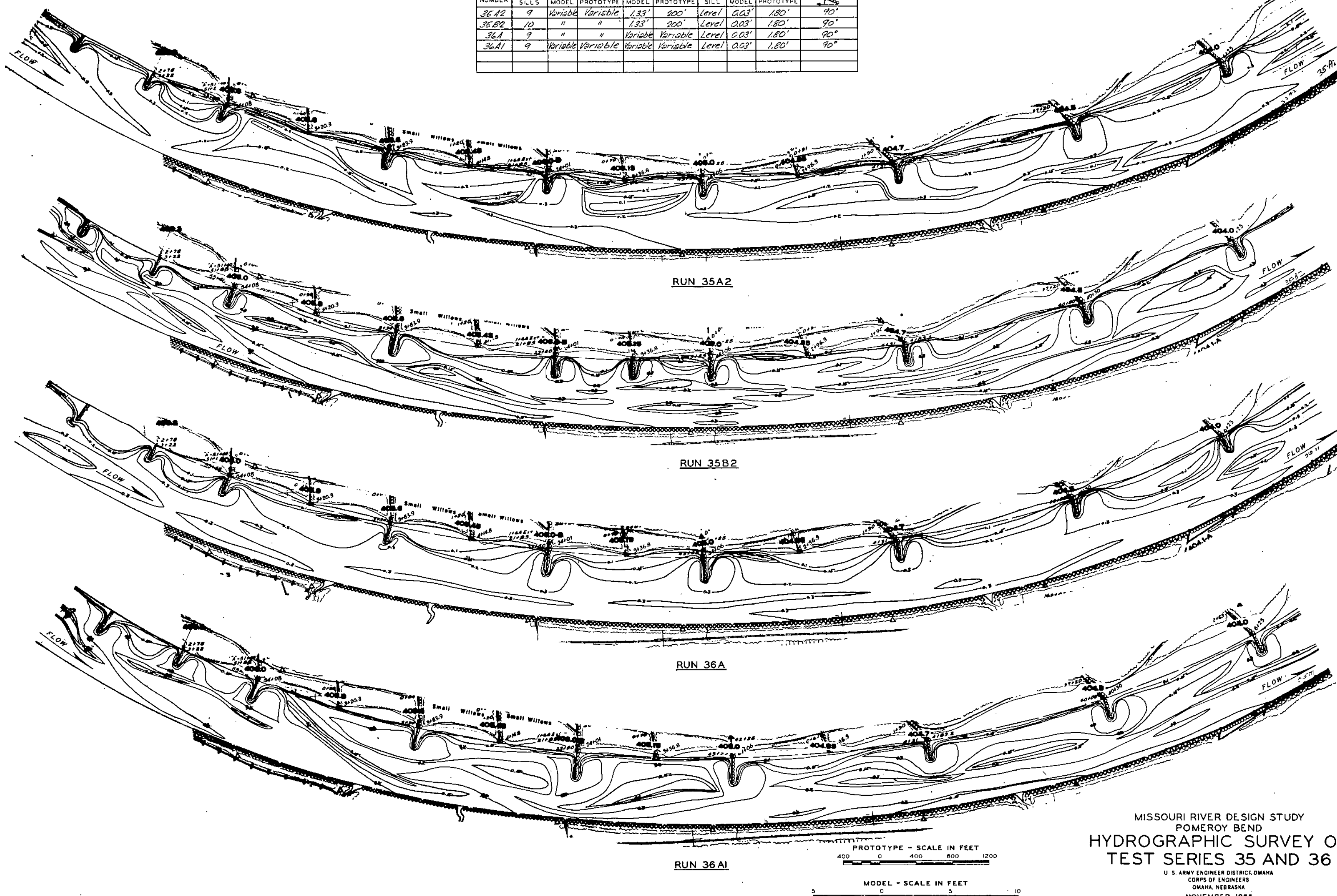
PROTOTYPE - SCALE IN FEET
400 0 400 800 1200

MODEL - SCALE IN FEET
5 0 5 10

MISSOURI RIVER DESIGN STUDY
POMEROY BEND
HYDROGRAPHIC SURVEY OF TEST SERIES 34
U S ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
NOVEMBER 1966

TEST INDEX

RUN NUMBER	NUMBER OF SILLS	SILL SPACING, FT		LENGTH OF SILLS, FT		CREST OF SILL	WATER OVER CREST, FT		ANGLE OF SILL TO FLOW
		MODEL	PROTOTYPE	MODEL	PROTOTYPE		MODEL	PROTOTYPE	
35A2	9	Variable	Variable	1.33'	200'	Level	0.03'	1.80'	90°
35B2	10	"	"	1.33'	200'	Level	0.03'	1.80'	90°
36A	9	"	"	Variable	Variable	Level	0.03'	1.80'	90°
36A1	9	Variable	Variable	Variable	Variable	Level	0.03'	1.80'	90°

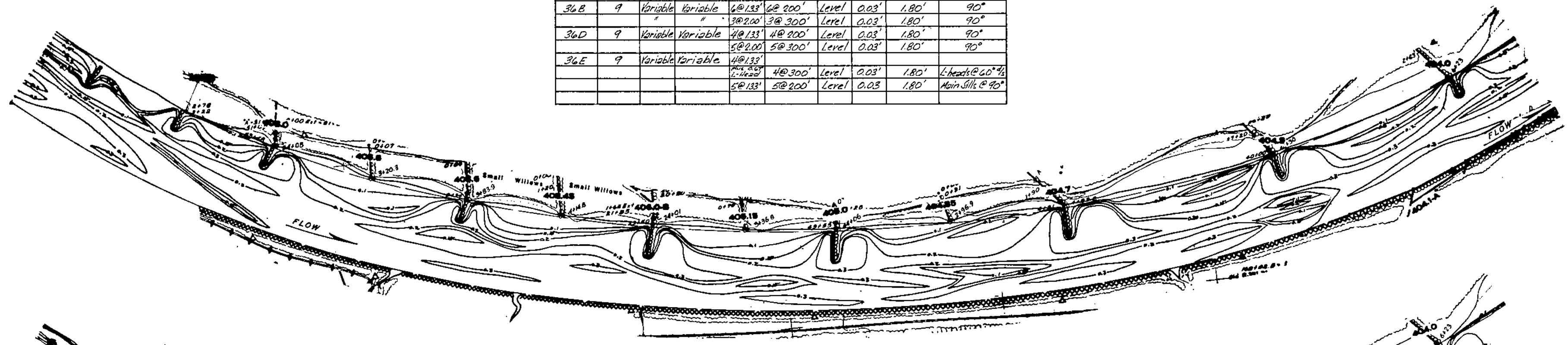


MISSOURI RIVER DESIGN STUDY
POMEROY BEND

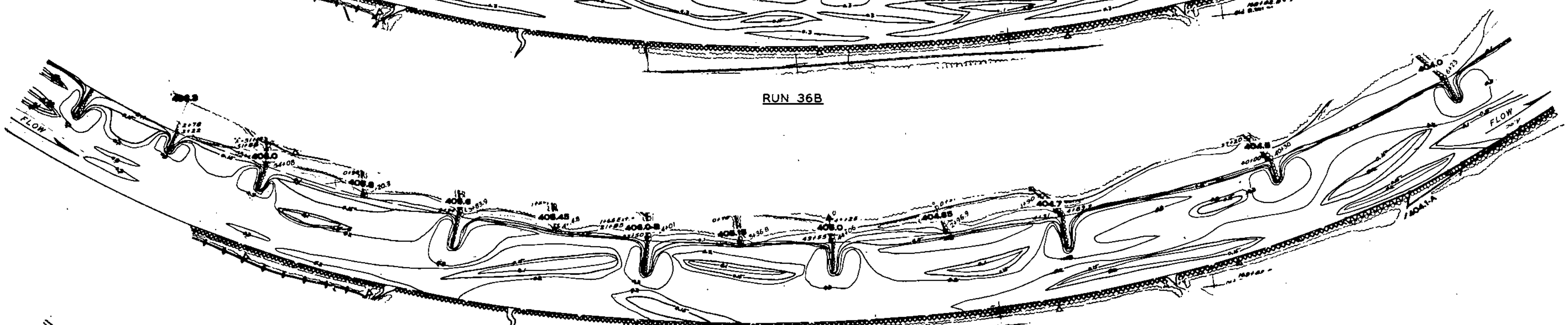
HYDROGRAPHIC SURVEY OF TEST SERIES 35 AND 36

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
NOVEMBER 1966

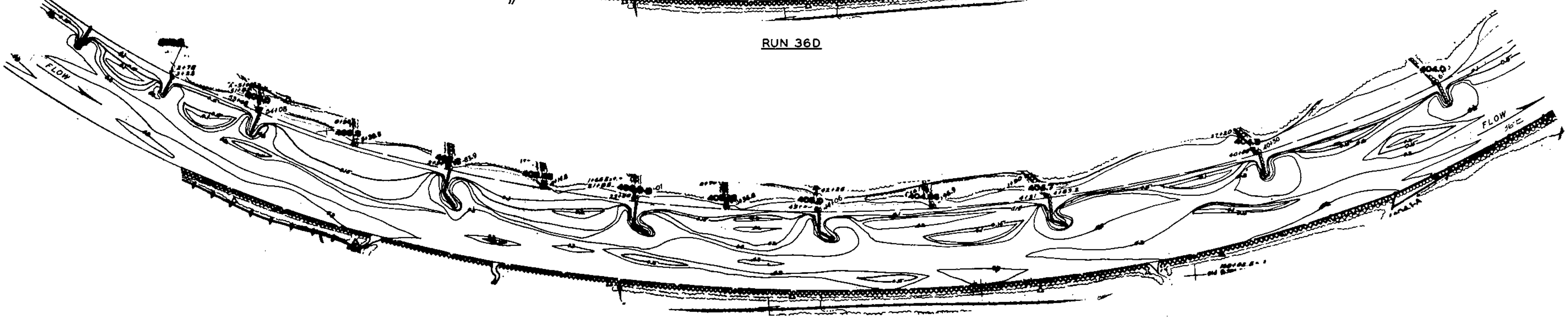
TEST INDEX									
RUN NUMBER	NUMBER OF SILLS	SILL SPACING, FT		LENGTH OF SILLS, FT		CREST OF SILL	WATER OVER CREST, FT		ANGLE OF SILL TO FLOW
		MODEL	PROTOTYPE	MODEL	PROTOTYPE		MODEL	PROTOTYPE	
36B	9	Variable	Variable	6@1.33'	6@200'	Level	0.03'	1.80'	90°
		"	"	3@2.00'	3@300'	Level	0.03'	1.80'	90°
36D	9	Variable	Variable	4@1.33'	4@200'	Level	0.03'	1.80'	90°
				5@2.00'	5@300'	Level	0.03'	1.80'	90°
36E	9	Variable	Variable	4@1.33'					
				Plus 0.67' L-Head	4@300'	Level	0.03'	1.80'	L-heads@60° u/s
				5@1.33'	5@200'	Level	0.03	1.80'	Main Sills @ 90°



RUN 36B



RUN 36D



RUN 36E

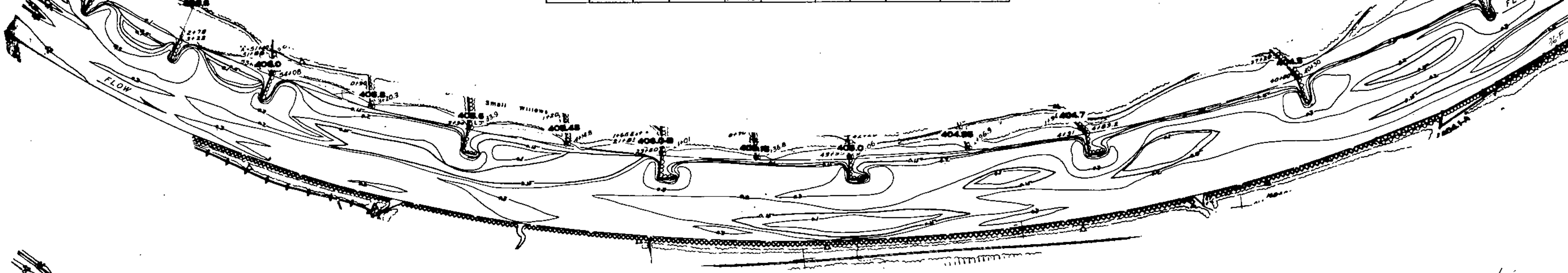
PROTOTYPE - SCALE IN FEET
400 0 400 800 1200

MODEL - SCALE IN FEET
5 0 5 10

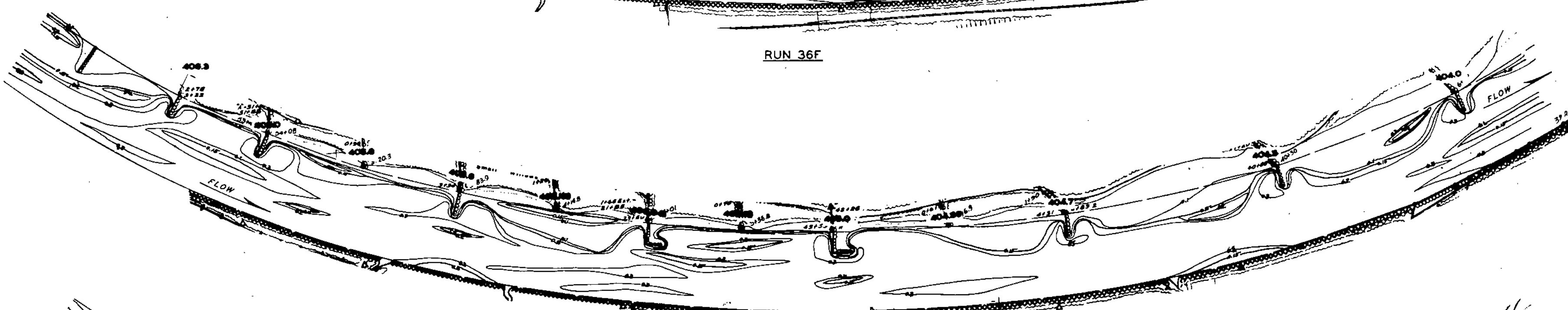
MISSOURI RIVER DESIGN STUDY
POMEROY BEND
HYDROGRAPHIC SURVEY OF
TEST SERIES 36

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
NOVEMBER 1966

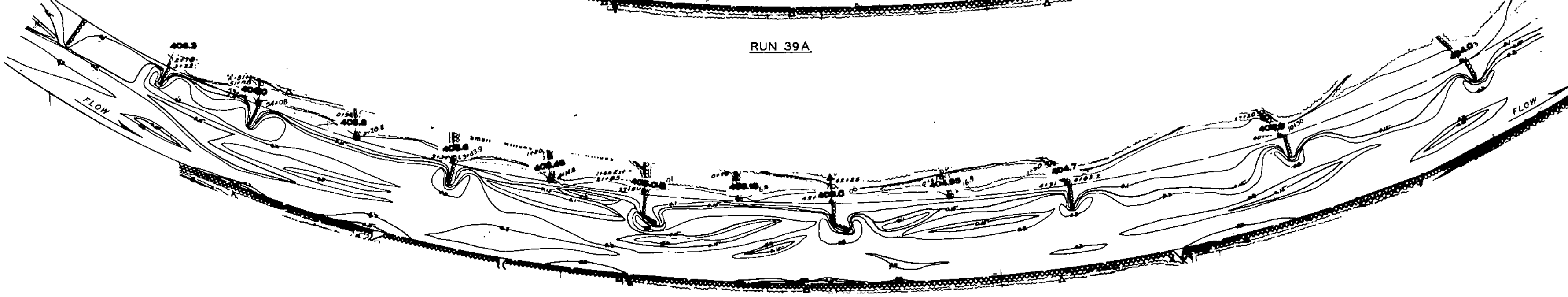
TEST INDEX									
RUN NUMBER	NUMBER OF SILLS	SILL SPACING, FT		LENGTH OF SILLS, FT		CREST OF SILL	WATER OVER CREST, FT		ANGLE OF SILL TO FLOW
		MODEL	PROTOTYPE	MODEL	PROTOTYPE		MODEL	PROTOTYPE	
36F	9	Variable	Variable	4@1.33' +0.67 Ext	300'	Level	0.03'	1.80'	Main sills @ 90° Extensions @ 0°
				5@1.33'	200'	Level	0.03'	1.80'	90°
39A	9	Variable	Variable	1@2.0'	300'	Level	0.03'	1.80'	90°
		"	"	2@1.33' +1.0 Ext.	450'	Level	0.03'	1.80'	Main sills @ 90° Extension @ 0°
		"	"	6@1.33'	200'	Level	0.03'	1.80'	90°
39B	9	Variable	Variable	1@2.0'	300'	Level	0.03'	1.80'	90°
		"	"	2@1.33' +1.0' Ext.	450'	Level	0.03'	1.80'	Main sills @ 90° Extension @ 60° d/s
		"	"	6@1.33'	200'	Level	0.03'	1.80'	90°



RUN 36F



RUN 39A



RUN 39B

PROTOTYPE - SCALE IN FEET
400 0 400 800 1200

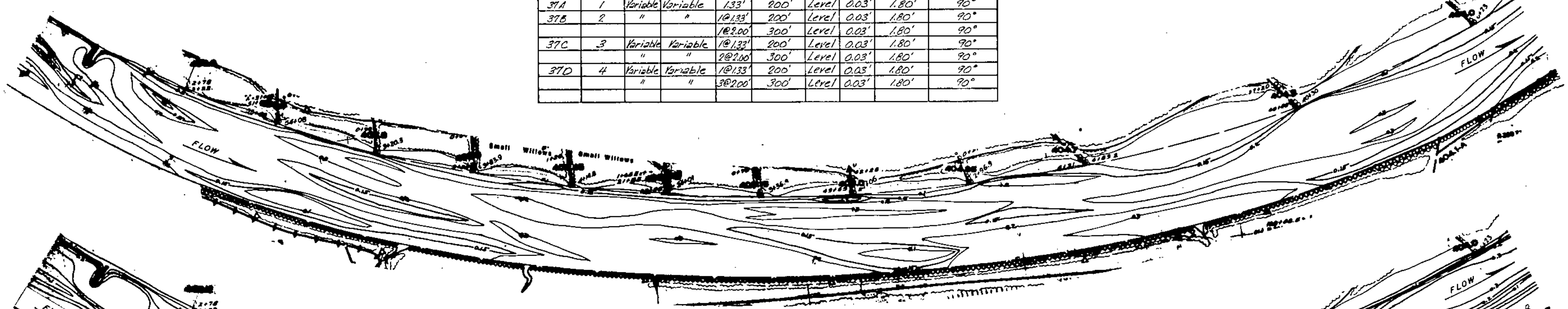
MODEL - SCALE IN FEET
5 0 5 10

MISSOURI RIVER DESIGN STUDY
POMEROY BEND

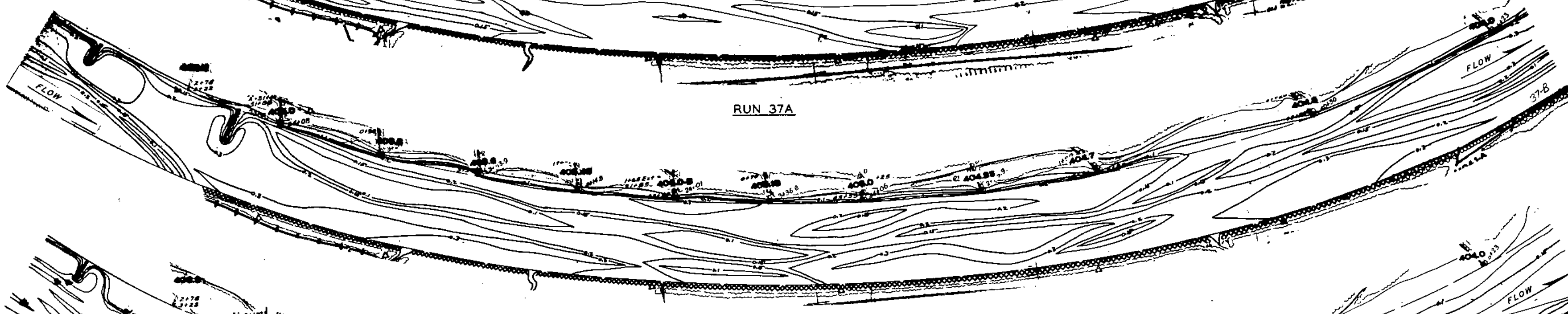
HYDROGRAPHIC SURVEY OF TEST SERIES 36 AND 39

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
NOVEMBER 1966

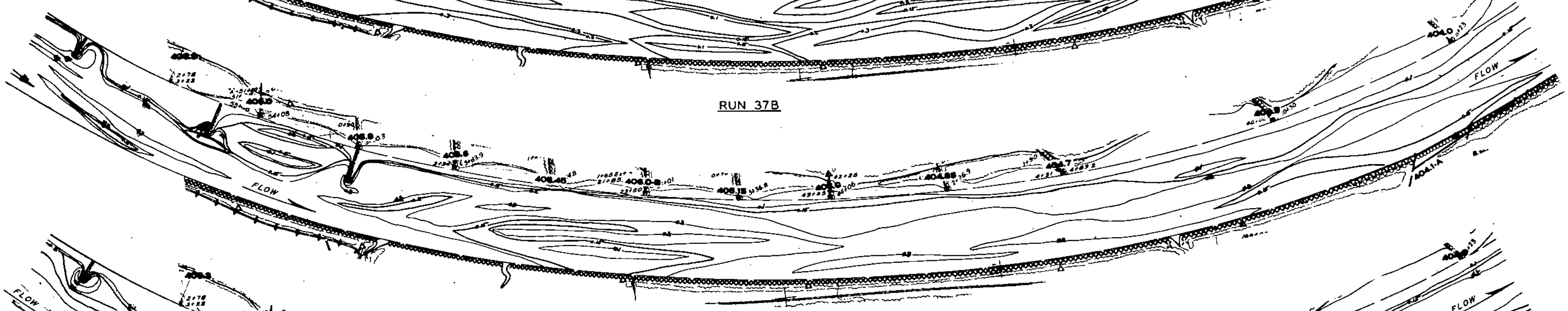
TEST INDEX								
RUN NUMBER	NUMBER OF SILLS	SILL SPACING, FT		LENGTH OF SILLS, FT		CREST OF SILL	WATER OVER CREST, FT		ANGLE OF SILL TO FLOW
		MODEL	PROTOTYPE	MODEL	PROTOTYPE		MODEL	PROTOTYPE	
37A	1	Variable	Variable	1.33'	200'	Level	0.03'	1.80'	90°
37B	2	"	"	1@1.33'	200'	Level	0.03'	1.80'	90°
				1@2.00'	300'	Level	0.03'	1.80'	90°
37C	3	Variable	Variable	1@1.33'	200'	Level	0.03'	1.80'	90°
		"	"	2@2.00'	300'	Level	0.03'	1.80'	90°
37D	4	Variable	Variable	1@1.33'	200'	Level	0.03'	1.80'	90°
		"	"	3@2.00'	300'	Level	0.03'	1.80'	90°



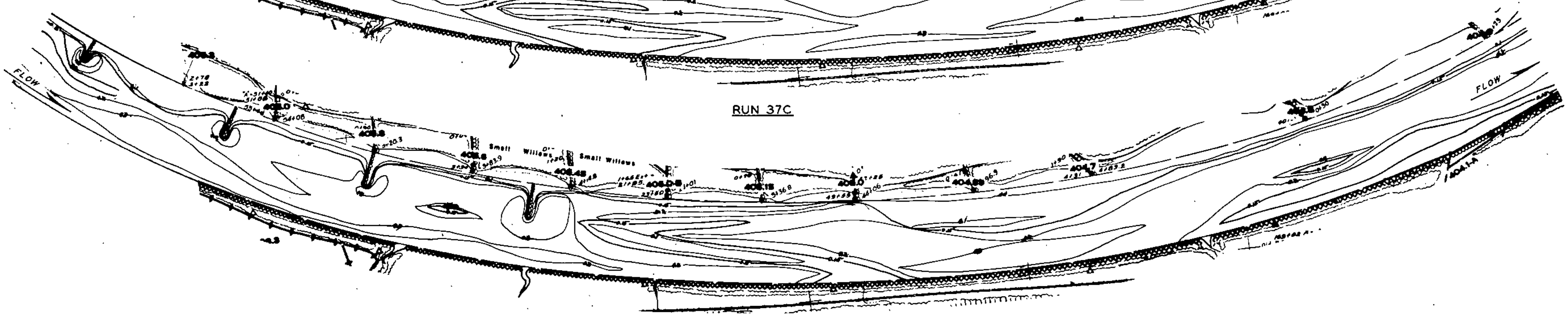
RUN 37A



RUN 37B



RUN 37C



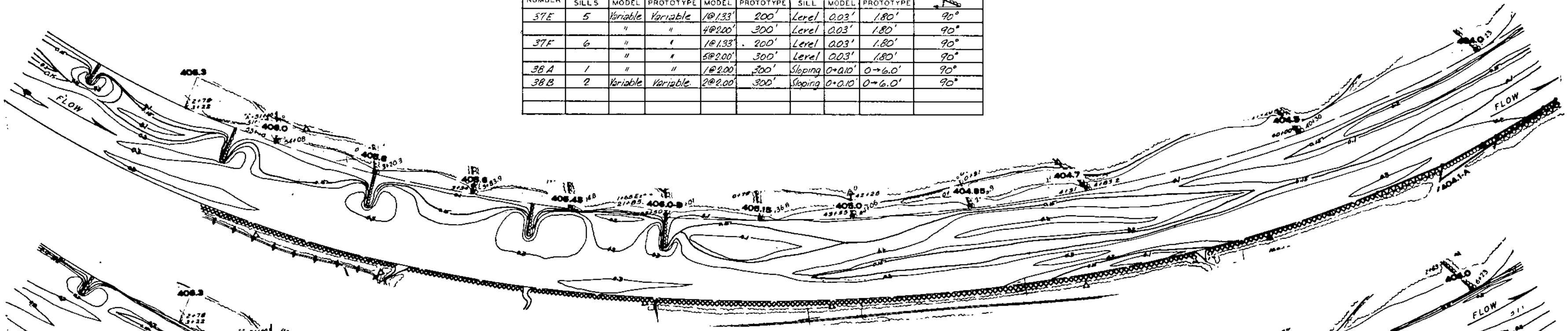
RUN 37D

PROTOTYPE - SCALE IN FEET
400 0 400 800 1200

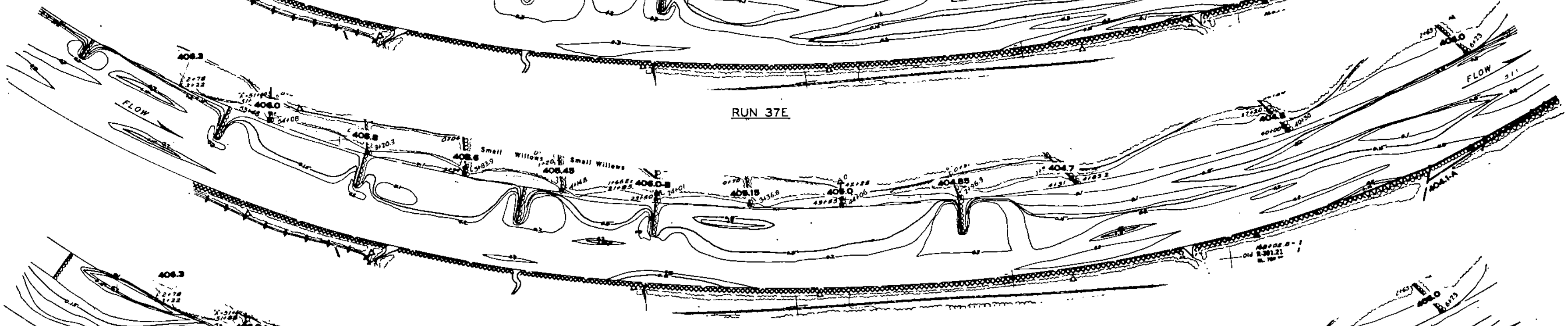
MODEL - SCALE IN FEET
5 0 5 10

MISSOURI RIVER DESIGN STUDY
POMEROY BEND
HYDROGRAPHIC SURVEY OF TEST SERIES 37
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
NOVEMBER 1966

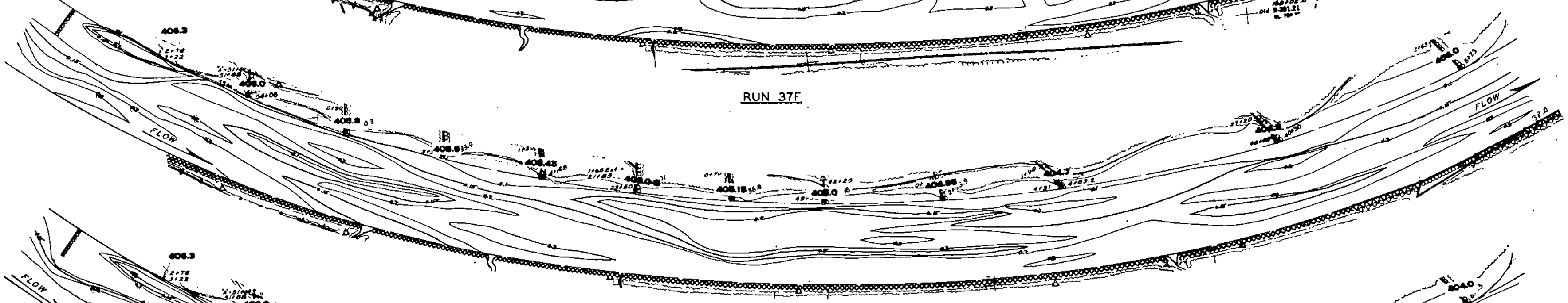
TEST INDEX									
RUN NUMBER	NUMBER OF SILLS	SILL SPACING, FT		LENGTH OF SILLS, FT		CREST OF SILL	WATER OVER CREST, FT		ANGLE OF SILL TO FLOW
		MODEL	PROTOTYPE	MODEL	PROTOTYPE		MODEL	PROTOTYPE	
37E	5	Variable	Variable	1@1.33'	200'	Level	0.03'	1.80'	90°
		"	"	4@2.00'	300'	Level	0.03'	1.80'	90°
37F	6	"	"	1@1.33'	200'	Level	0.03'	1.80'	90°
		"	"	5@2.00'	300'	Level	0.03'	1.80'	90°
38A	1	"	"	1@2.00'	300'	Sloping	0→0.10'	0→6.0'	90°
38B	2	Variable	Variable	2@2.00'	300'	Sloping	0→0.10'	0→6.0'	90°



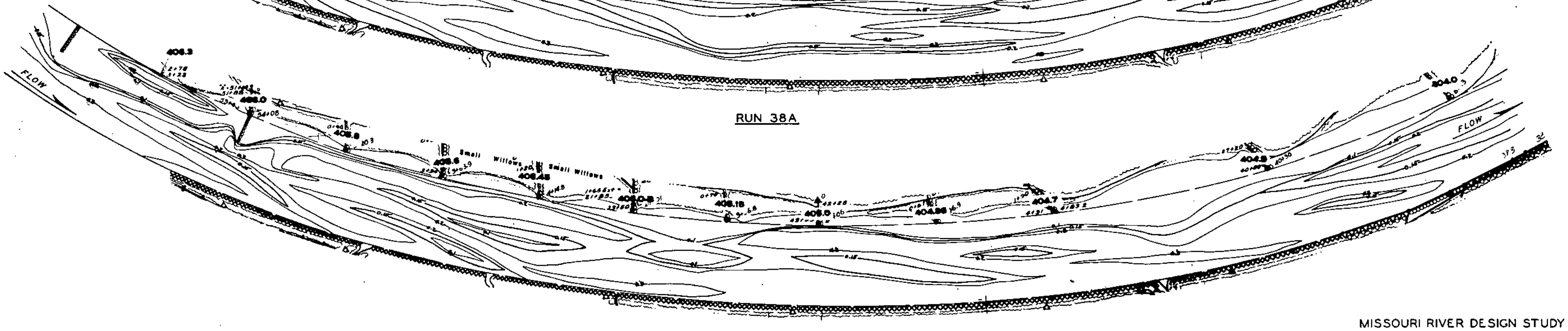
RUN 37E



RUN 37F



RUN 38A



RUN 38B

PROTOTYPE - SCALE IN FEET

400 0 400 800 1200

MODEL - SCALE IN FEET

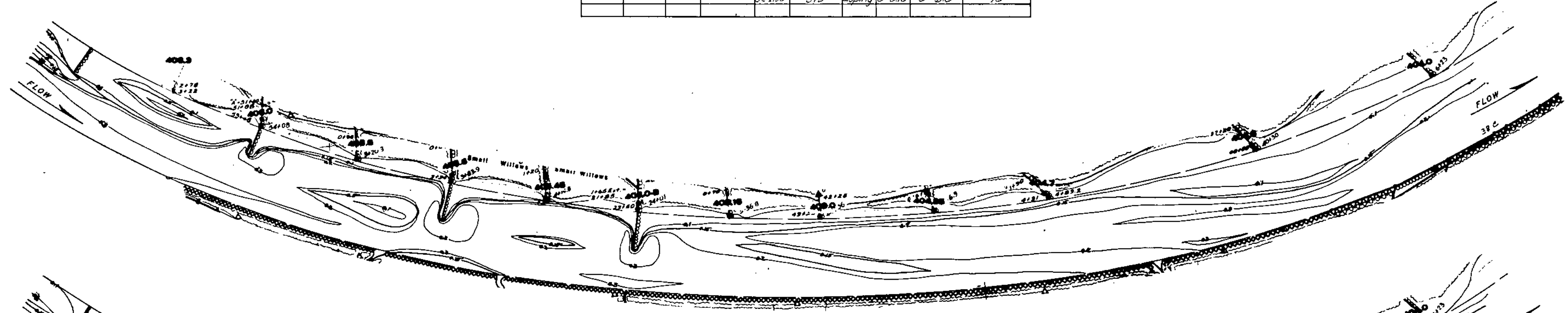
5 0 5 10

MISSOURI RIVER DESIGN STUDY
POMEROY BEND

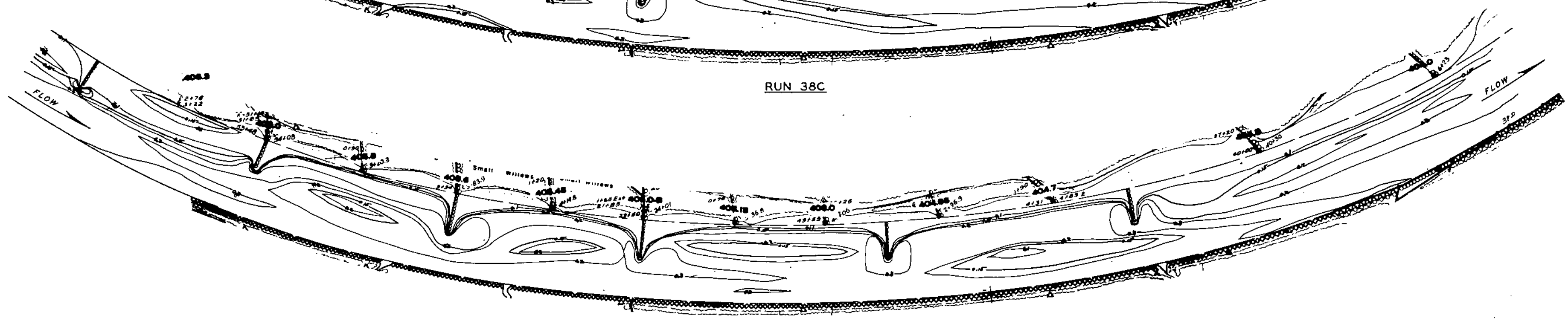
HYDROGRAPHIC SURVEY OF TEST SERIES 37 AND 38

U S ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
NOVEMBER 1966

TEST INDEX									
RUN NUMBER	NUMBER OF SILLS	SILL SPACING, FT		LENGTH OF SILLS, FT		CREST OF SILL	WATER OVER CREST, FT		ANGLE OF SILL TO FLOW
		MODEL	PROTOTYPE	MODEL	PROTOTYPE		MODEL	PROTOTYPE	
38 C	4	Variable	Variable	2@2.00'	300'	Sloping	0→0.10'	0→6.0'	90°
		"	"	2@2.50'	375'	"	0→0.10'	0→6.0'	90°
38 D	6	Variable	Variable	3@2.00'	300'	"	0→0.10'	0→6.0'	90°
		"	"	3@2.50'	375'	Sloping	0→0.10'	0→6.0'	90°



RUN 38C



RUN 38D

PROTOTYPE - SCALE IN FEET
400 0 400 800 1200

MODEL - SCALE IN FEET
5 0 5 10

MISSOURI RIVER DESIGN STUDY
POMEROY BEND
HYDROGRAPHIC SURVEY OF
TEST SERIES 38
U S ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
NOVEMBER 1966